Long-Baseline Neutrino Experiment

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for the LBNE Collaboration

"Snowmass" Community Summer Study 2013
University of Minnesota
August 1st, 2013

Overview

- Scientific Motivation
- Neutrino Mixing
- LBNE Collaboration
- LBNE Science
- LBNE Design Status
- Towards a World Class Facility
- Summary

Further details:
"Science Opportunities w/ LBNE", arXiv:1307.7335, SNOW13-00081.

Scientific Motivation

- Neutrinos are the most abundant known matter particle
- Neutrino (Flavor) Oscillation is a quantum interference phenomenon with as yet unknown implications for fundamental physics
  - **known neutrino mass and mixing angle values allow quantum interferometry on a continental scale sensitive to minute effects**
- Neutrino mass cannot be understood within the Standard Model – calls for new physics
- Our knowledge of neutrino properties is based on only a handful of direct measurements. Future precision measurements need to test the 3-generation picture and models of neutrino mass and mixing

Scientific Motivation

- CP Violation in neutrino sector?
  - Violation of a fundamental symmetry; viability of leptogenesis models
- Neutrino Mass Hierarchy
  - GUTs, Dirac vs. Majorana nature and feasibility of $0\nu\beta\beta$ decay
- Testing the Three-Flavor Paradigm
  - Precision measurements of known fundamental mixing parameters
  - New physics -> non-standard interactions, sterile neutrinos… (with beam + atmospheric ν sources)
  - Precision neutrino interactions studies (near detector)

Scientific Motivation

- Other fundamental physics enabled by massive detectors
  - Proton decay measurement
    - Grand Unification Theory
  - Astrophysics
    - Supernova ν burst flux

LBNE Collaboration

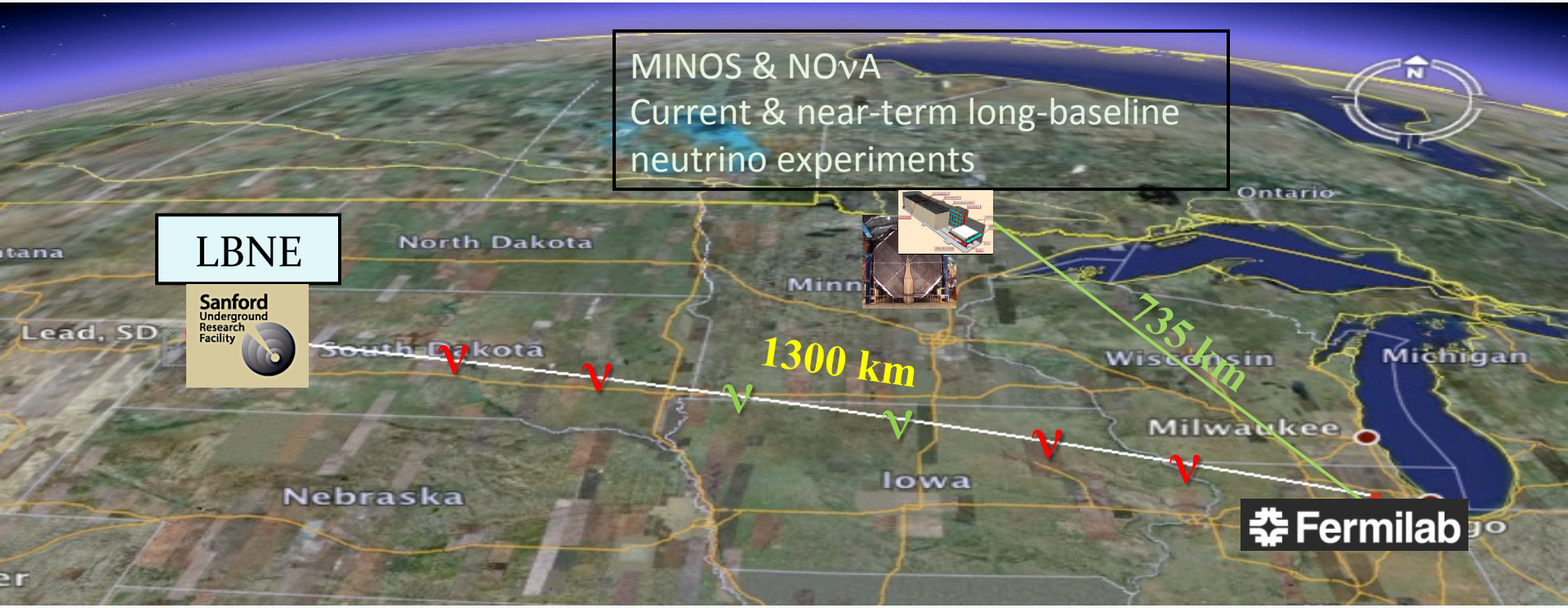
Alabama
Argonne
Boston
Brookhaven
Cambridge
Catania
Columbia
Chicago
Colorado
Colorado State
Columbia
Dakota State
Davis
Drexel
Duke
Duluth
Fermilab
Hawaii
Indian Group
Indiana
Iowa State
Irvine
Kansas State
Kavli/IPMU-Tokyo
Lawrence Berkeley NL
Livermore NL
London UCL
Los Alamos NL
Louisiana State
Maryland
Michigan State
Minnesota
MIT

- 372 members, 61 institutions, 5 countries (April 2013)
- Applications from ~8 institutions/40 members being prepared
- Co-spokespersons Milind Diwan (BNL), Bob Wilson (CSU)

Fermilab, March 2013

NGA
New Mexico
Northwestern
Notre Dame
Oxford
Pennsylvania
Pittsburgh
Princeton
Rensselaer
Rochester
Sanford Lab
Sheffield
SLAC
South Carolina
South Dakota
South Dakota State
SDSMT
Southern Methodist
Sussex
Syracuse
Tennessee
Texas, Arlington
Texas, Austin
Tufts
UCLA
Virginia Tech
Washington
William and Mary
Wisconsin
Yale

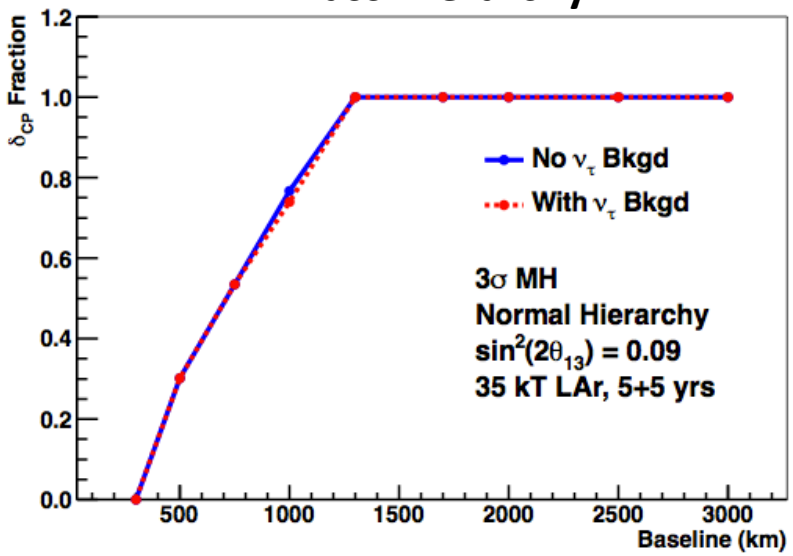
LBNE – Optimal Baseline



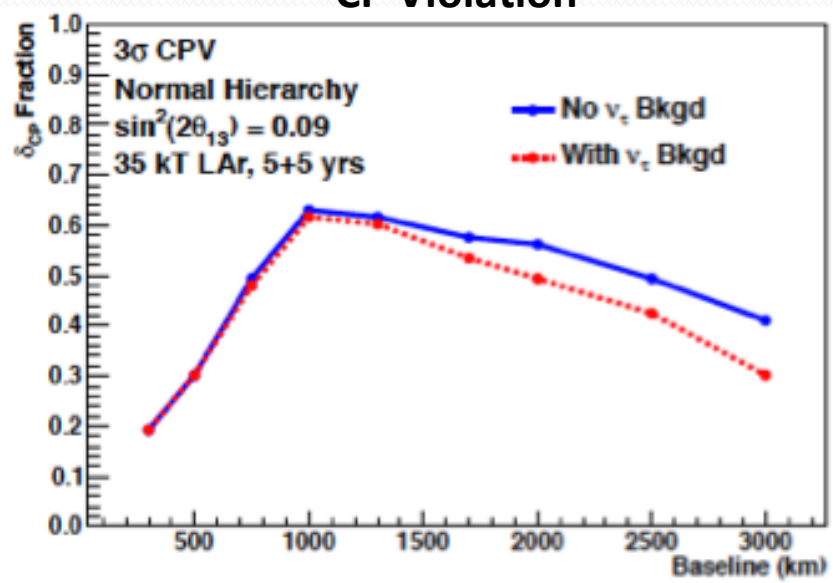
Baseline Optimization

Detailed calculation with horn based realistic beam optimization at each baseline and assumption of liquid argon TPC of 35 kt. Assume 120 GeV protons at 700kW.

Mass Hierarchy



CP Violation



- The LBNE design with a 1300 km, 120 GeV proton beam, on-axis LArTPC far detector is economical for a comprehensive oscillation program
- Any other choice will necessitate larger detector or higher beam intensity

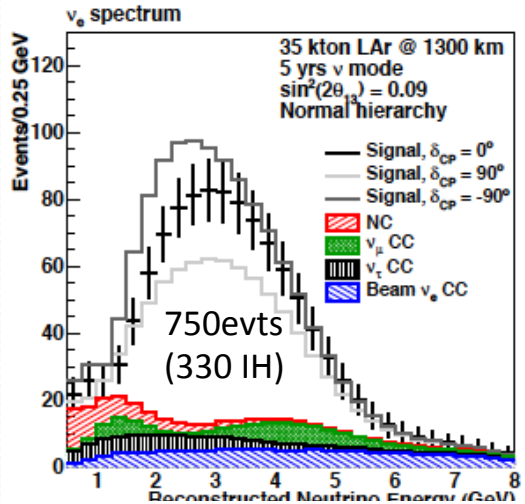
Long-Baseline Measurements & Oscillation Parameter Sensitivities

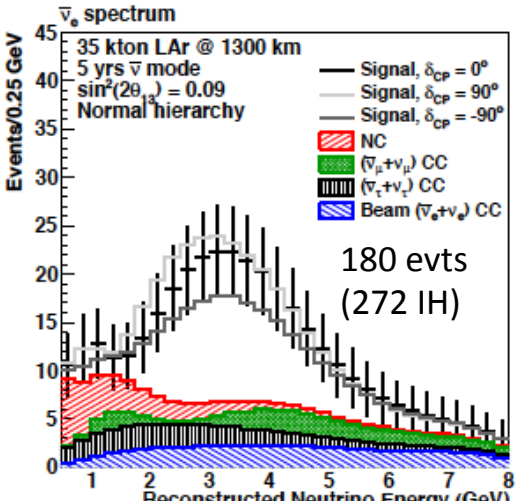
LBNE 34 kt Spectra

ν (5 yrs) $\bar{\nu}$ (5 yrs)

Appearance

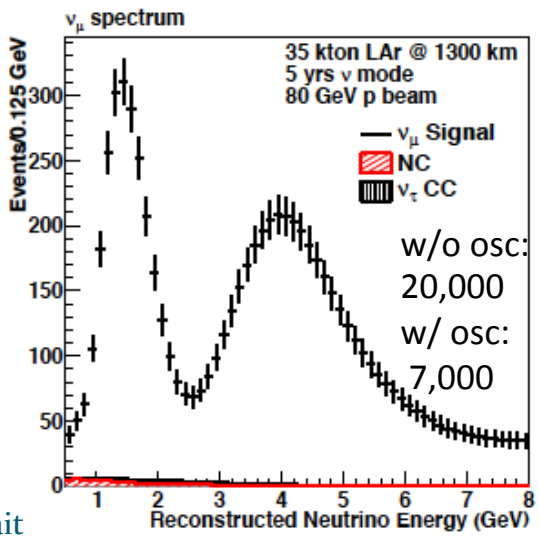
$\nu_\mu \rightarrow \nu_e$

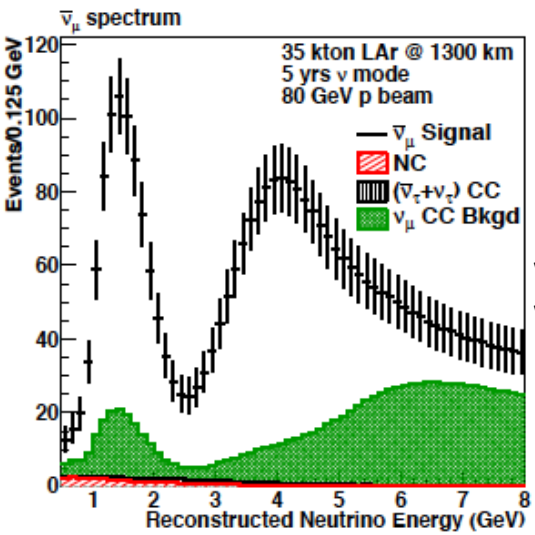




Disappearance

$\nu_\mu \rightarrow \nu_\mu$



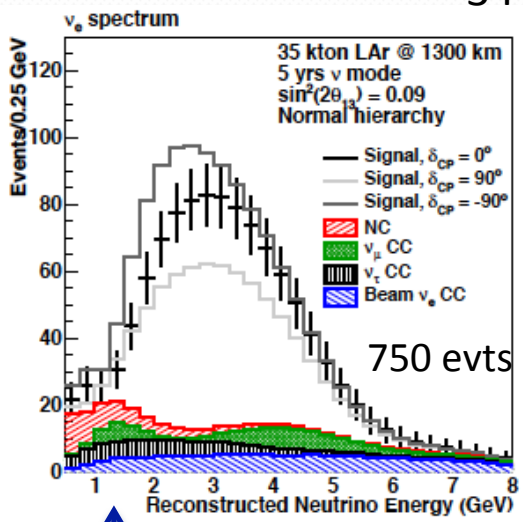


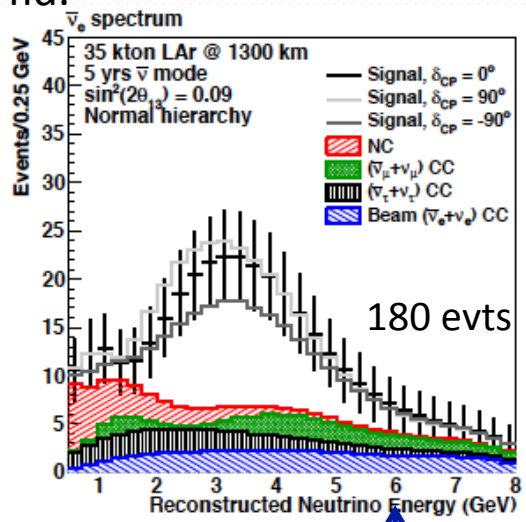
w/o osc: 6,700
w/ osc: 2,200

LBNE Spectra-Mass Hierarchy

34 kt fid.

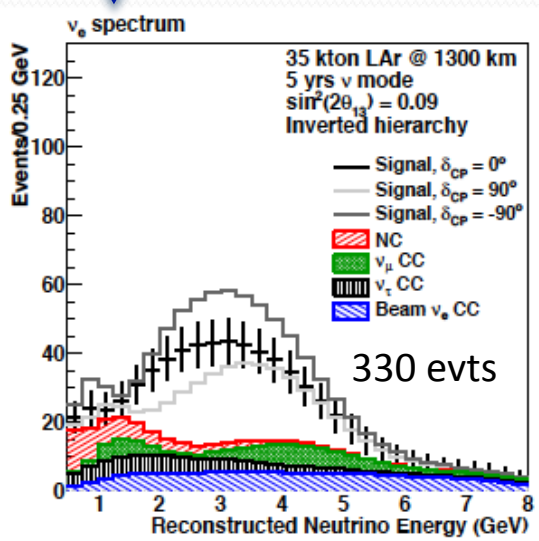
Normal

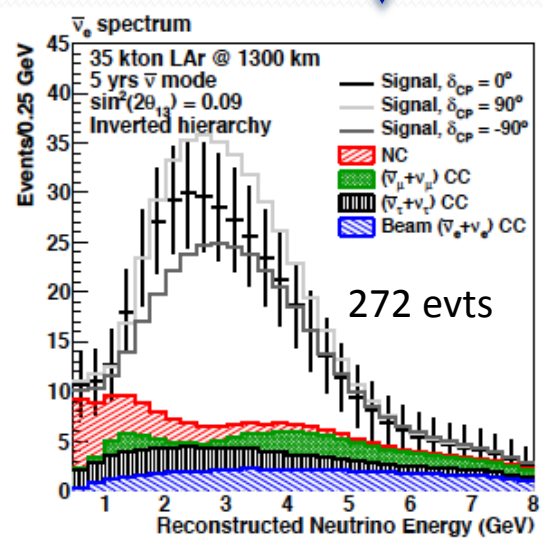




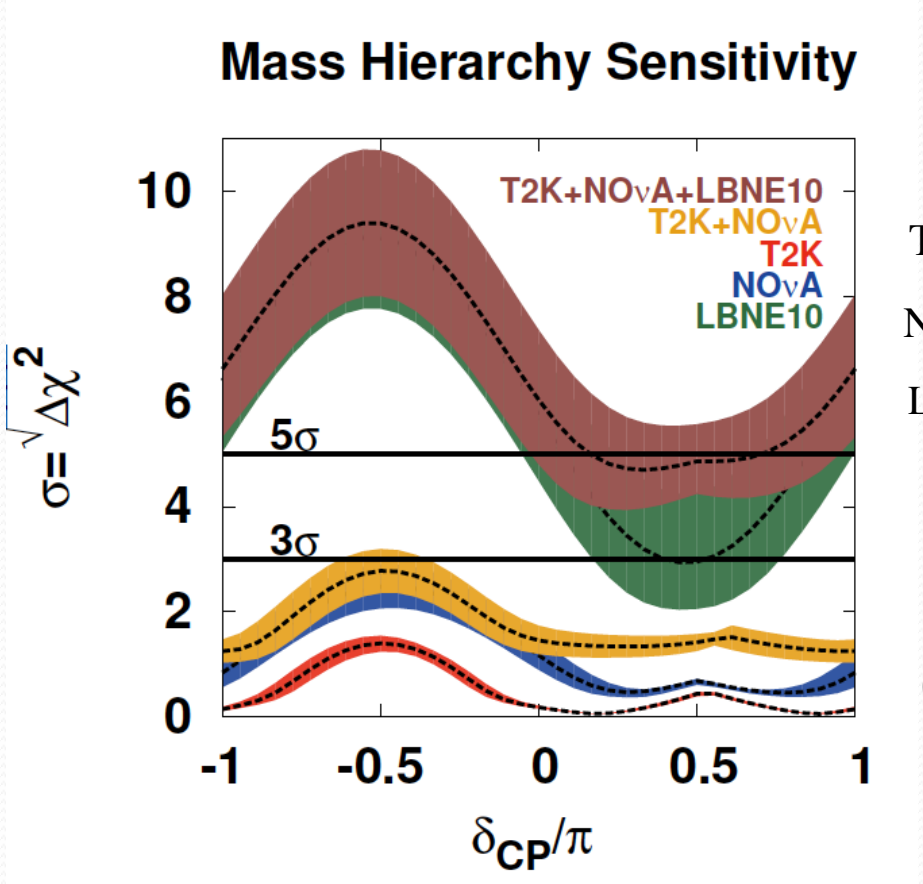
Difference due to mass ordering

Inverted





Just 10 kt LArTPC Would be a Major Advance



T2K 750 kW x 5 yr (7.8×10^{21}pot) ν

NOνA 700 kW x (3 yr ν + 3 yr $\bar{\nu}$) (3.8×10^{21}pot)

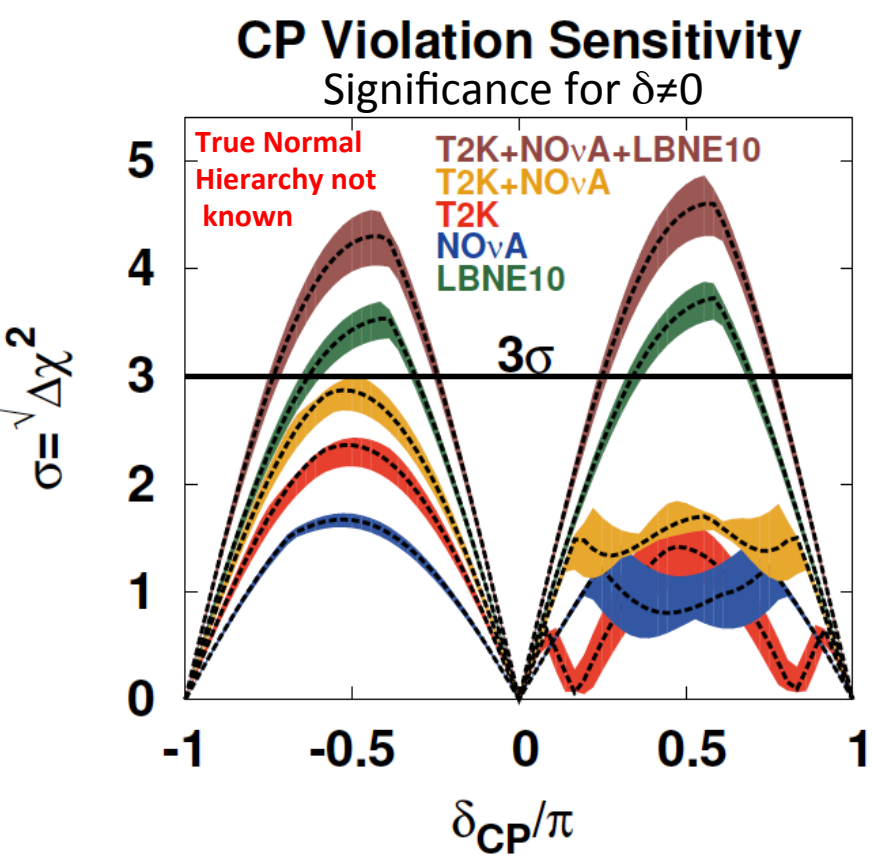
LBNE10 (80 GeV*) 700 kW x (5 yr ν + 5 yr $\bar{\nu}$)

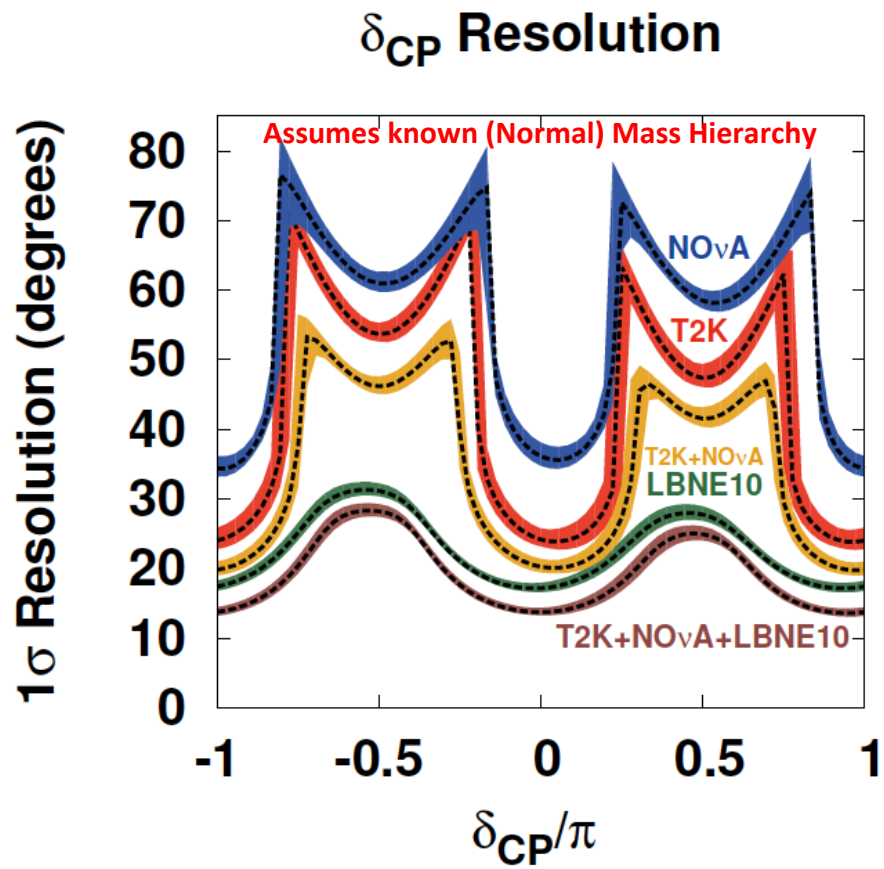
*Improved over CDR 2012 120 GeV MI proton beam

Bands: 1σ variations of θ_{13}, θ_{23}, Δm_{31}^2
(Fogli et al. arXiv:1205.5254v3)

- LBNE10 does much better than full program for existing experiments

Just 10 kt LArTPC Would be a Major Advance





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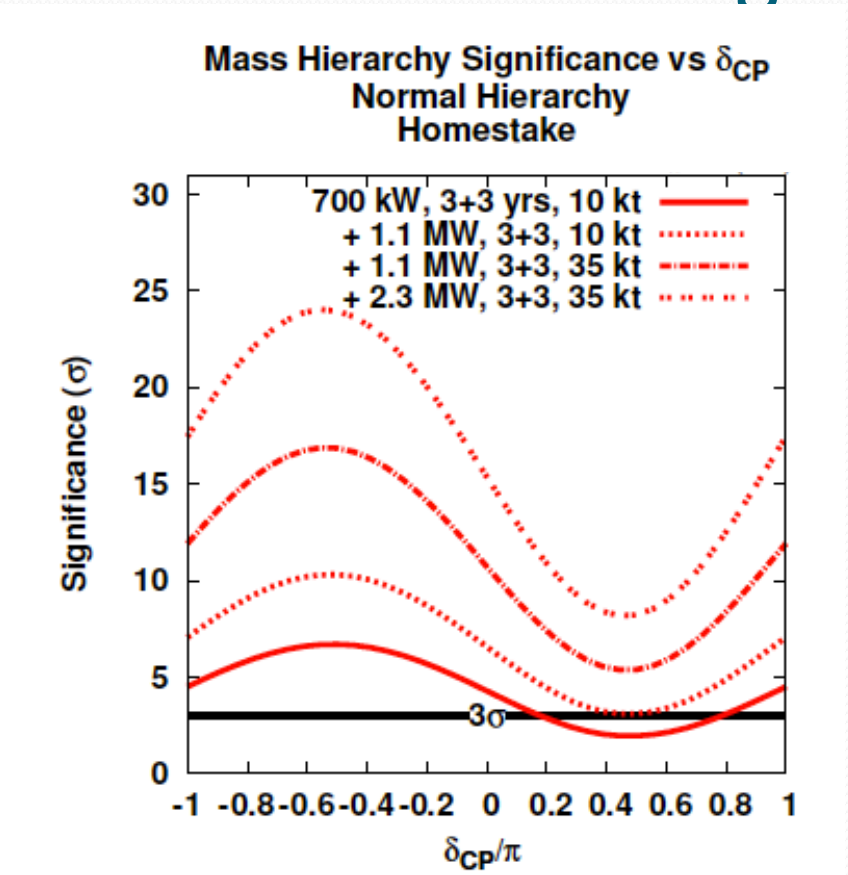
LBNE + Project X (1.1-2.3 MW) = Comprehensive Global Science Program

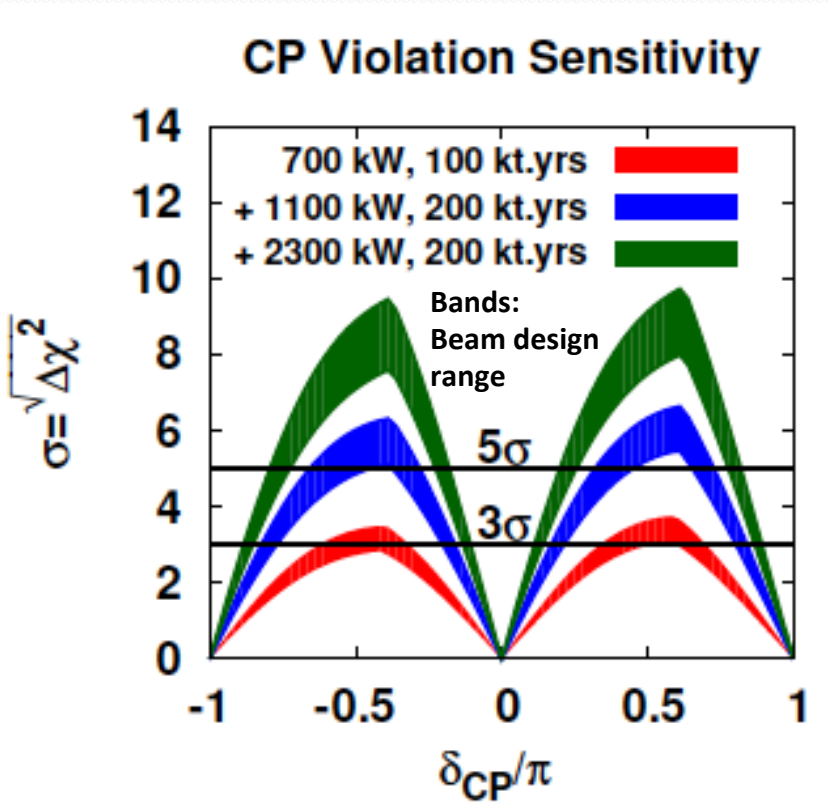
Run scenario:

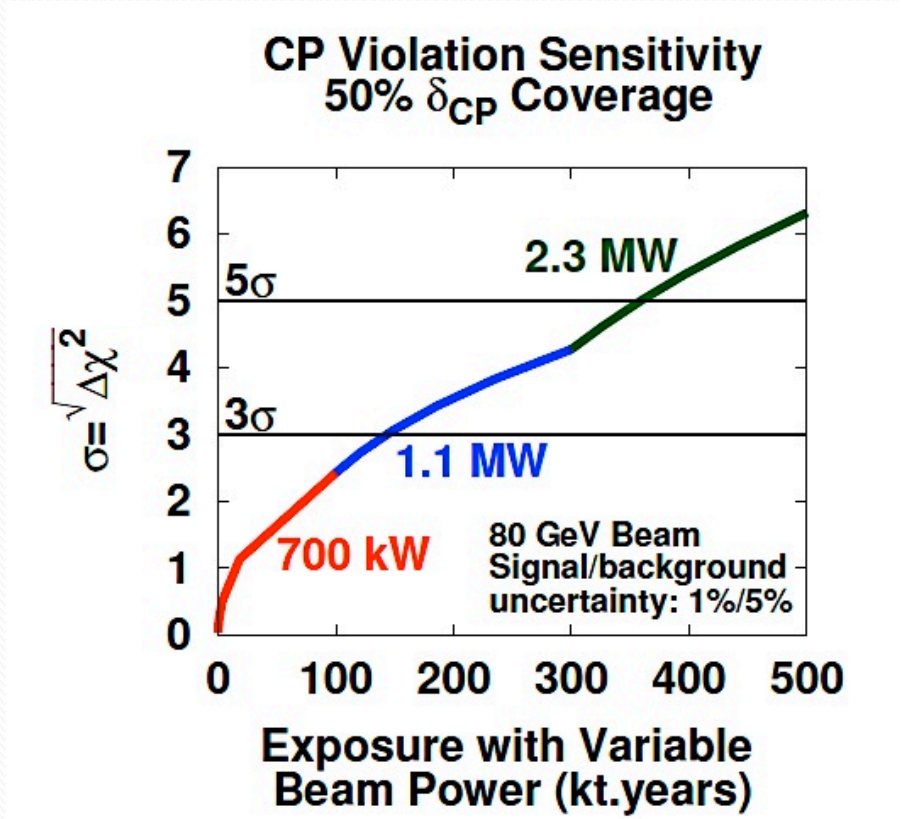
- Operate w/ 700 kW w/ 10 kt LBNE
- Then 1.1 MW 1st phase Project X
- Add 25 kt LBNE FD
- Then 2.3 MW 2nd phase Project X



- With the Mass Hierarchy unambiguously determined in the same experiment more subtle matter effect features may be revealed

LBNE + Project X (1.1-2.3 MW) = Comprehensive Global Science Program

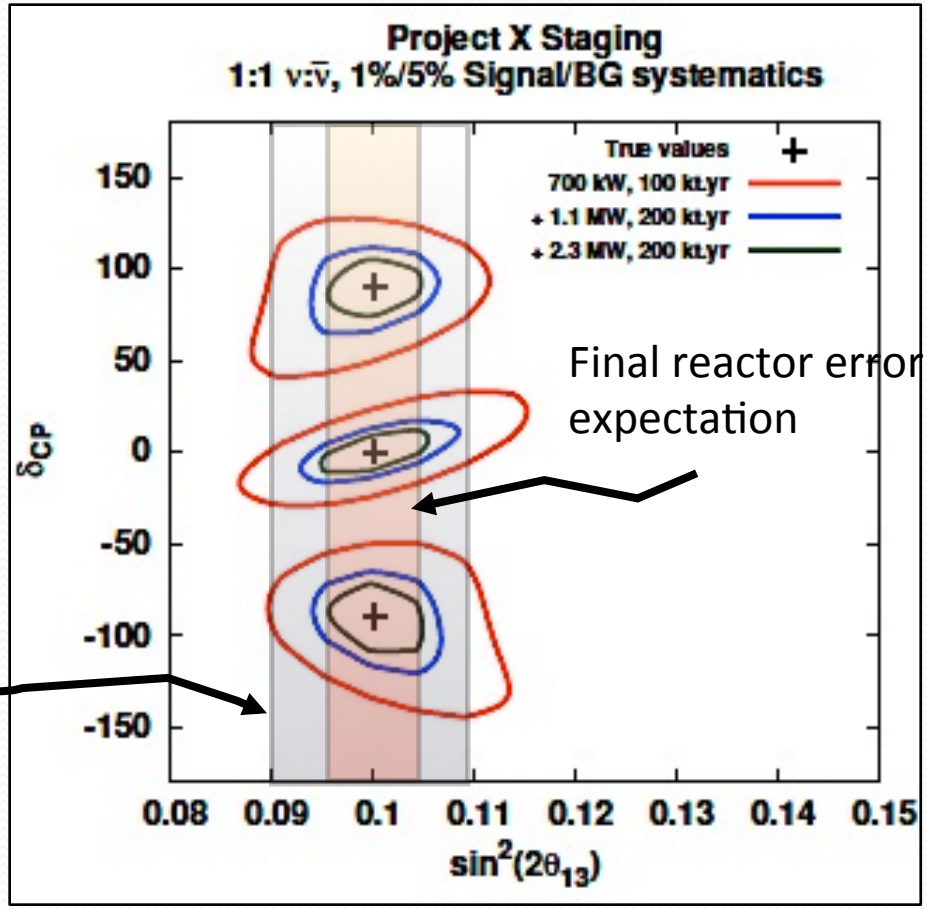




With 80 GeV MI protons source

- Long-range program in tandem with near detector neutrino interactions and non-accelerator physics

LBNE + Project X (1.1-2.3 MW) = Comprehensive Global Science Program

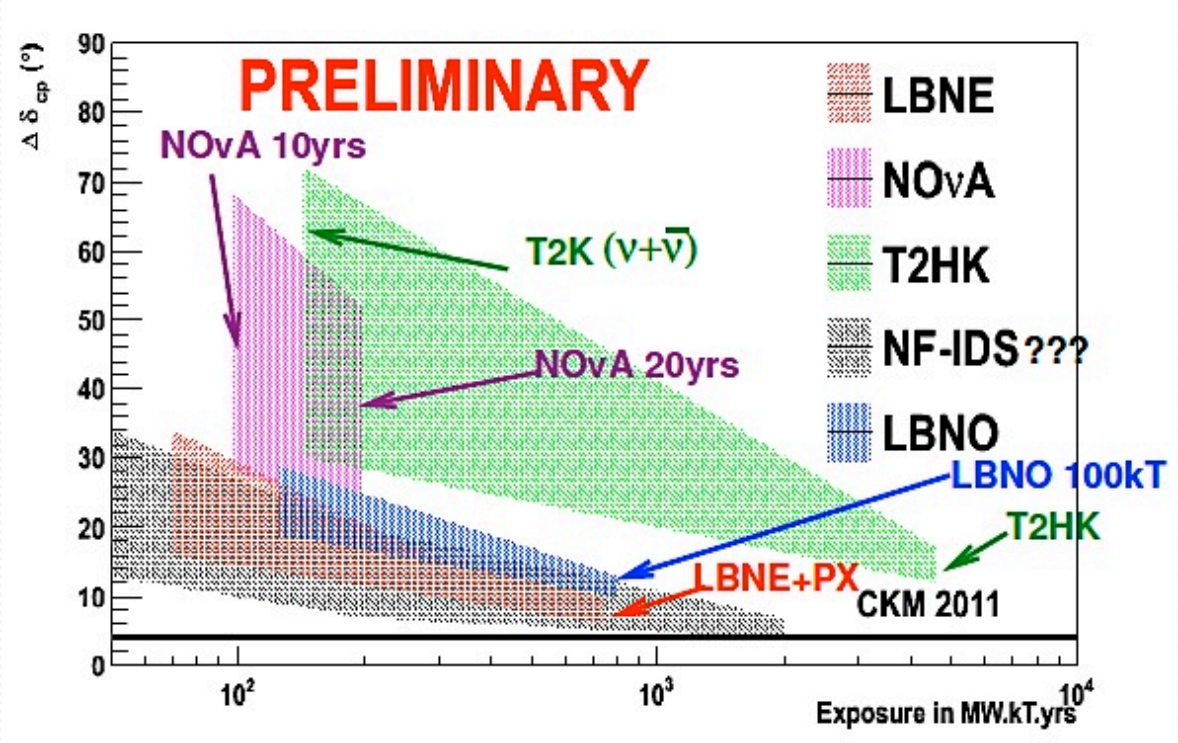


Final reactor error expectation

Current reactor error

Global Context

Bands: Range of δ_{CP} (best-worst case)



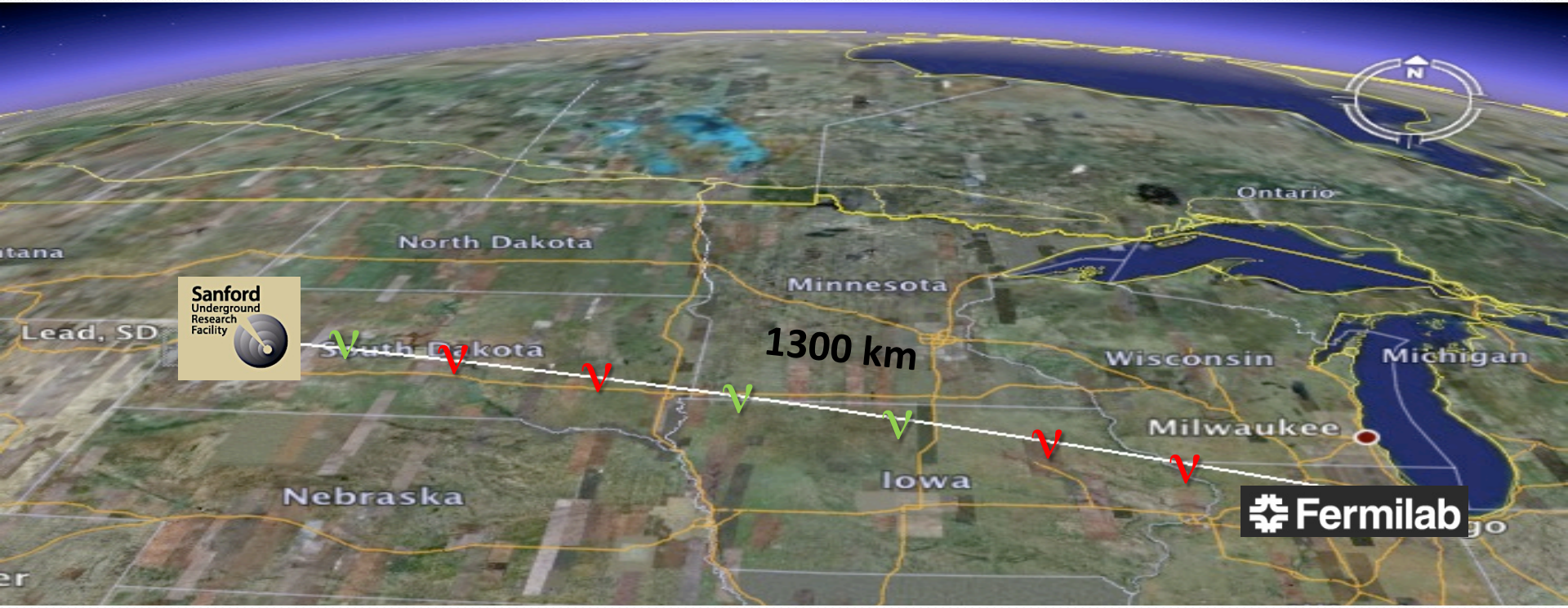
NF-IDS entry has assumptions about conversion from muon rate to POT and beam power

- LBNE+Project X will ultimately approach CKM level of precision

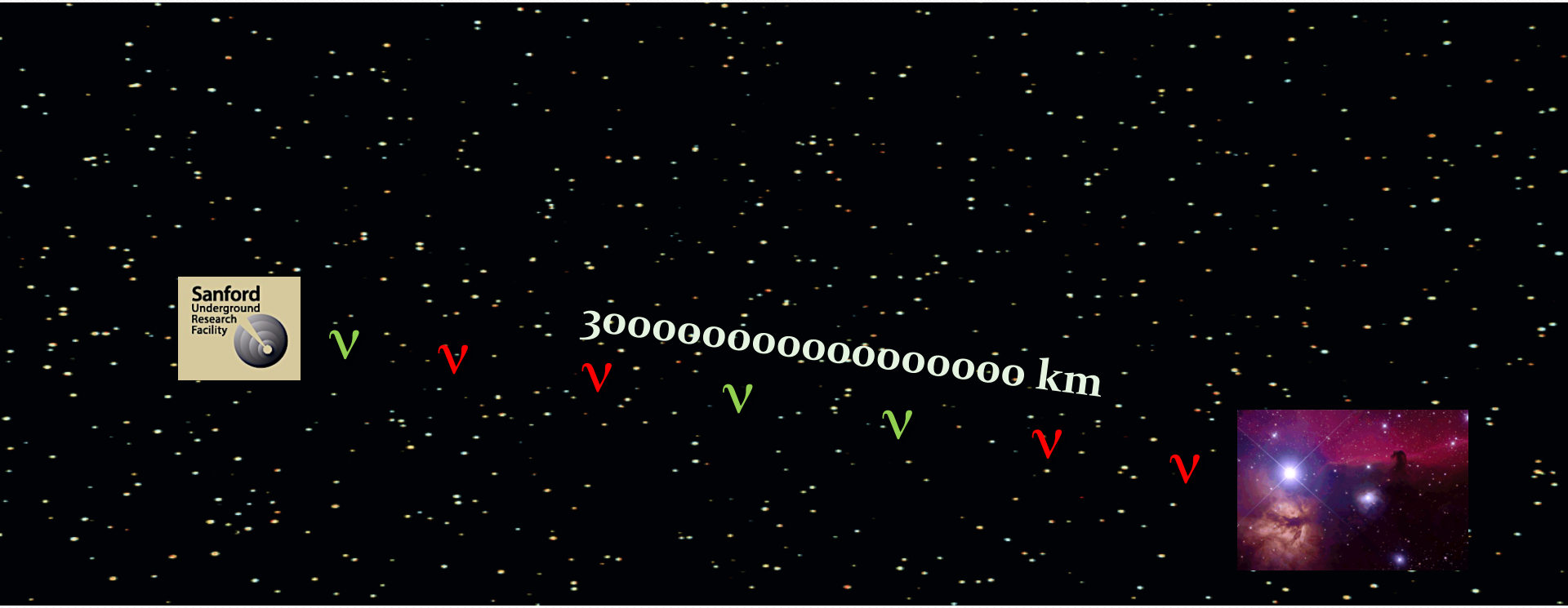
Non-Beam Physics

- Supernova Burst Neutrinos
- Proton Decay
- Atmospheric Neutrinos

Deep Underground Science

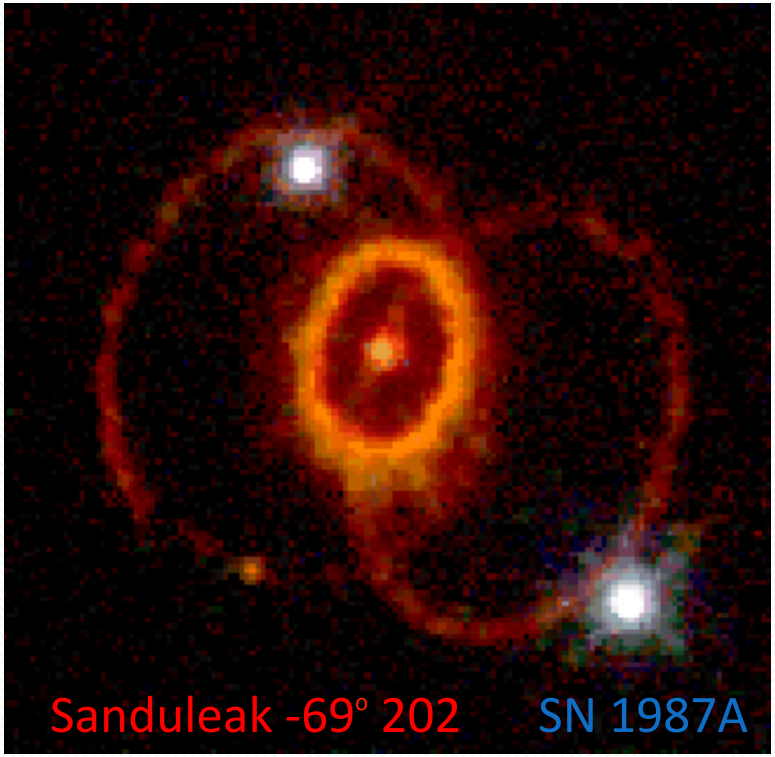


Supernova Burst Neutrinos



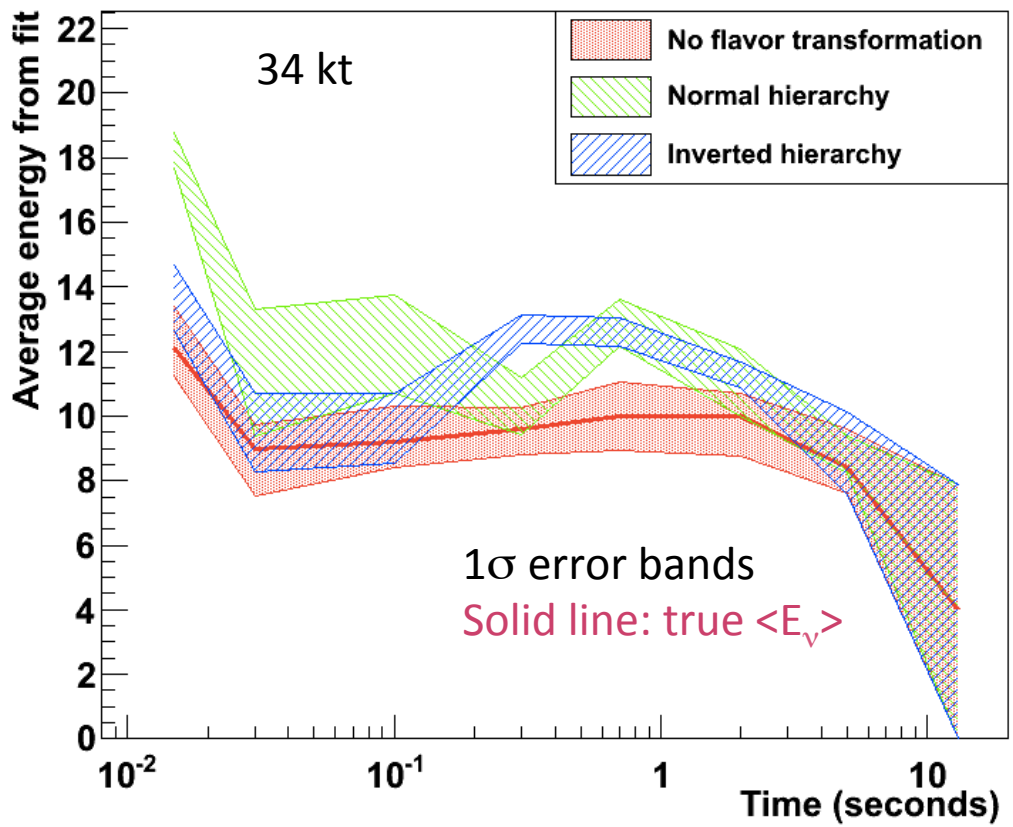
Supernova Burst Neutrinos

- When a star's core collapses ~99% of the gravitational binding energy of the proto-neutron star goes into ν's
- SN at galactic core (10 kpc) $\Rightarrow$ few thousand interactions in 20 kt LArTPC in tens of seconds (ν_e detection complementary to WCD)
- **SN 1987A observation of ~20 events → ~800 publications!**



Measuring SN ν_e temperature vs. time

Preliminary: work in progress



- 10 kpc spectra from A. Friedland/JJ Cherry/H. Duan smeared w/ SNOwGLoBES response, fit to pinched thermal spectrum
- Based on Keil, Raffelt, Janka spectra, astro-ph/0208035, w/ collective oscillations (NH & IH)

Proton Decay

General Remarks

Discovery of proton decay would provide unambiguous evidence for Baryon Number (B) violation

B violation is essential for creation of matter in the Universe

Proton decay controls the ultimate fate of the Universe

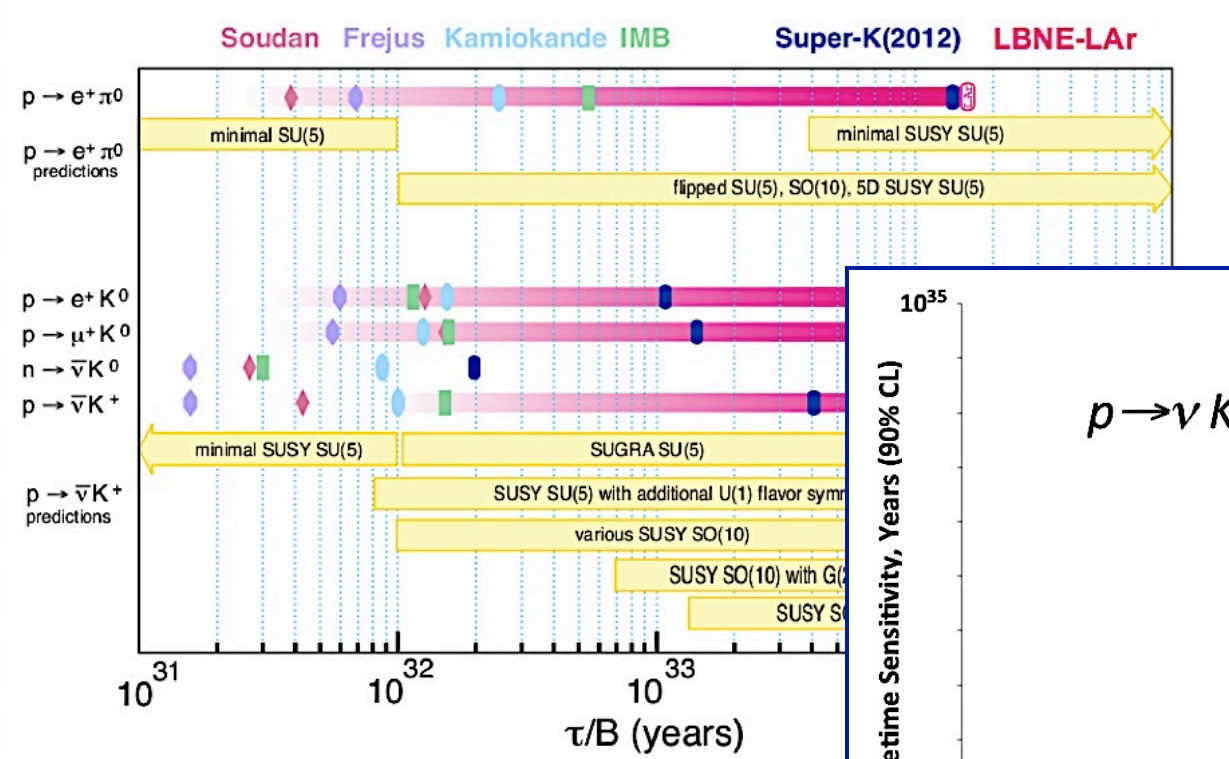
Proton decay is the missing link of Grand Unitied Theories for which strong circumstantial evidence exists

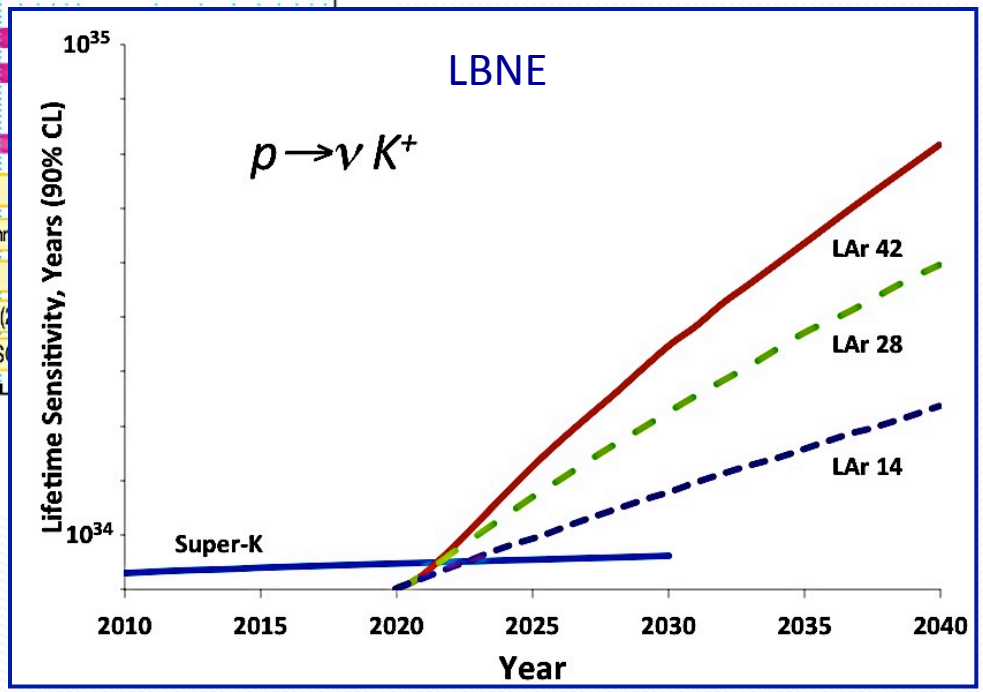
Discovery of proton decay would be a monumental scientific achievement for mankind

Large Underground Detectors are absolutely essential in acheiving this goal

K. Babu, ISOUPs, Asilomar June 2013

Proton Decay



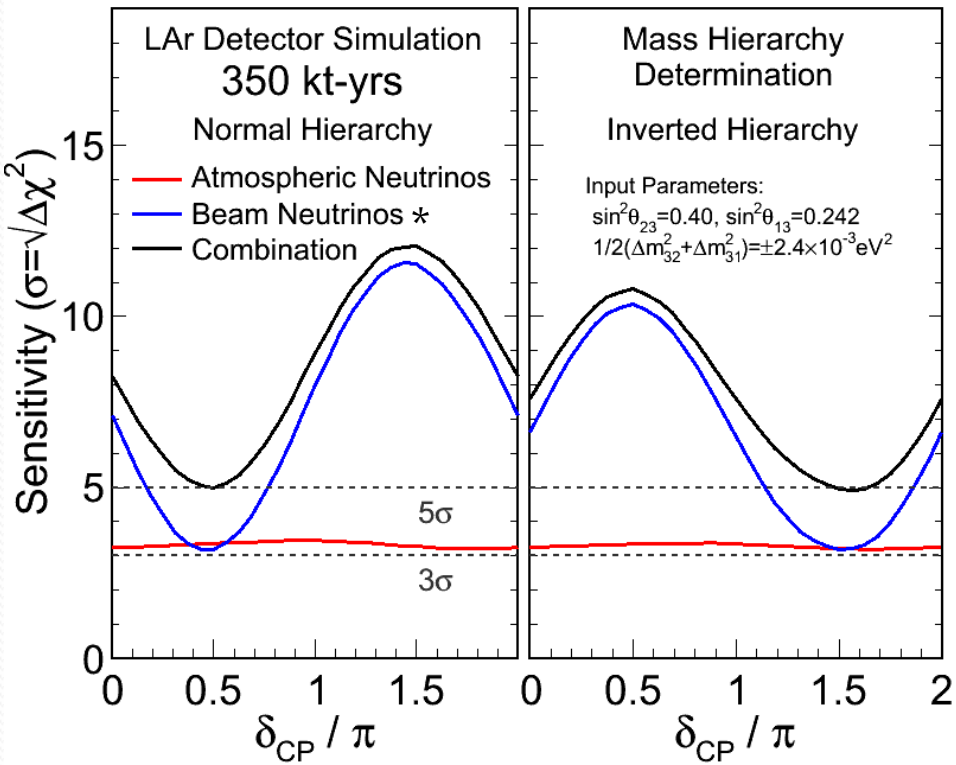


- LAr TPC high efficiency for kaon modes
- Especially interesting if SUSY discovered at LHC

Adapted from a plot by E. Kearns

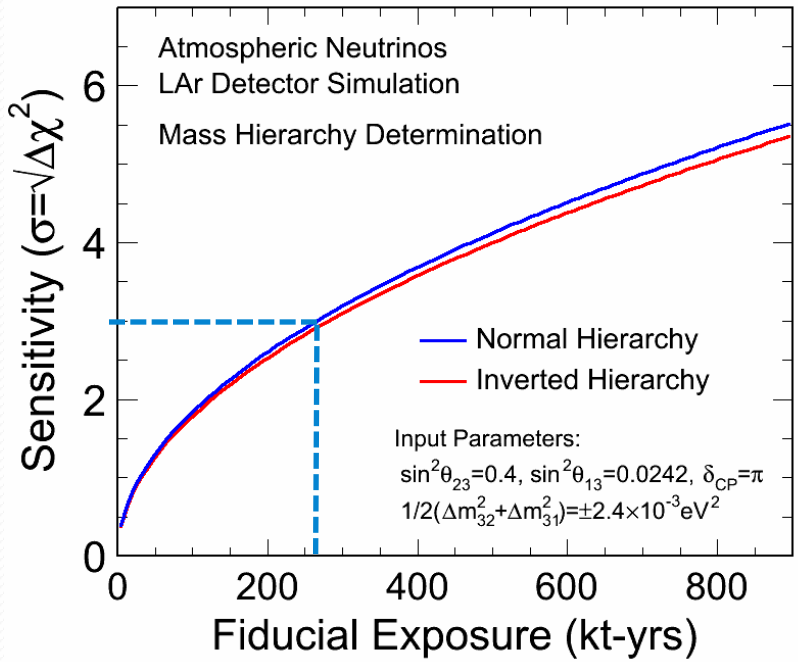
Atmospheric Neutrinos

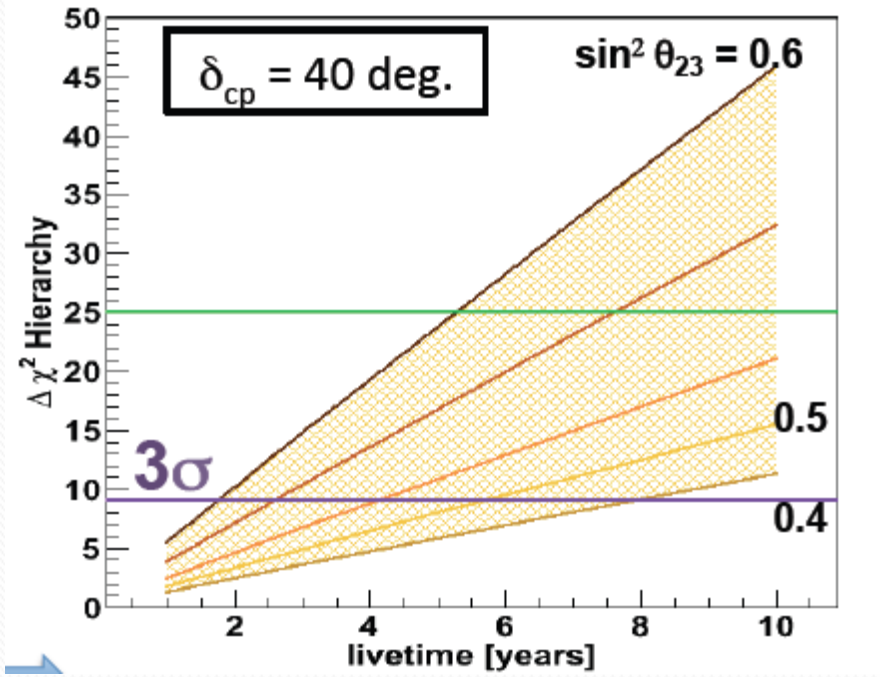
- **Large range of energy and baseline**
- In δ_{CP} range least favorable to the beam, atmospheric neutrinos have MH sensitivity comparable to the beam
- Help eliminate degeneracies in beam-only analyses
- MH from atmospheric neutrinos alone is >3σ for both hierarchies and all values of δ_{CP} in 350 kt-yrs
- **Combined sensitivity is >5σ for both hierarchies and all values of δ_{CP} in 350 kt-yrs.**
- Searches for new physics



- * Conceptual Design Report beam
- ~4000 e-like, 6000 μ-like fully-contained events
- Proton and decay-electron tagging for Atm. nus calculation

Atmospheric Neutrinos





LBNE MH Sensitivity

(H. Gallagher + A. Blake*)

HyperK MH Sensitivity

(C. Walter*)

- **HyperK and LBNE have comparable sensitivity to the MH with atmospheric neutrinos!**
- LBNE's higher resolution of event energy and direction makes up for smaller mass.

*ISOUPs, May 2013

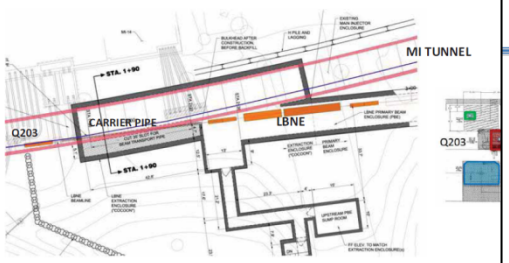
LBNE Design Status

LBNE has a well-developed design for the complete project:

- Neutrino beam at Fermilab for 700 kW operation, upgradeable to 2.3 MW
- Highly-capable near neutrino detector on the Fermilab site
- 34 kt fiducial mass LAr far detector at
  - A baseline of 1300 km
  - A depth of 4300 m.w.e. at the Sanford Underground Research Facility (SURF)

LBNE Neutrino Beamline

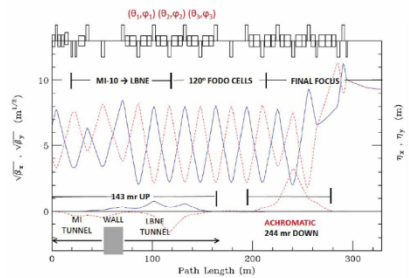
MI-10 Extraction



Transport from the existing MI tunnel enclosure into the new LBNE encl
showing the carrier pipe connecting the MI-10 & LBNE enclosures (left),
and separation of Q203 at the upstream end from the Main Injector & Re
Rings (right).

LBNE CD-1 DOE Review – 30 Oct - 1 Nov 2012

Lattice Functions

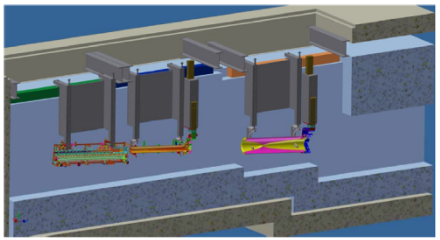


Horizontal (solid) and vertical (dashed) lattice functions of the LBNE transfer

LBNE CD-1 DOE Review – 30 Oct - 1 Nov 2012

Horn Systems – Module Design

- Modules are used to support the Horns and Target carrier.*
- Also supports the stripline block; located on the D.S. face.
- Provide all utilities and alignment mechanisms for each device.



* Conceptual module design done by Larry Bartoszek.

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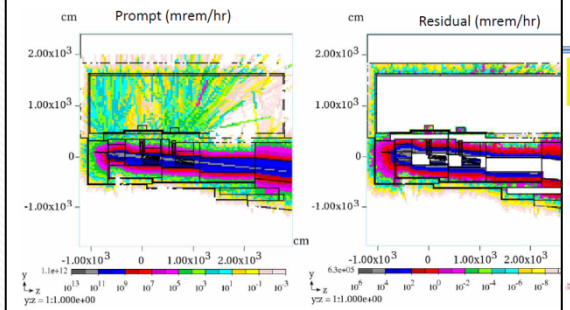
Modeling: Prompt and Residual dose at Target Hall

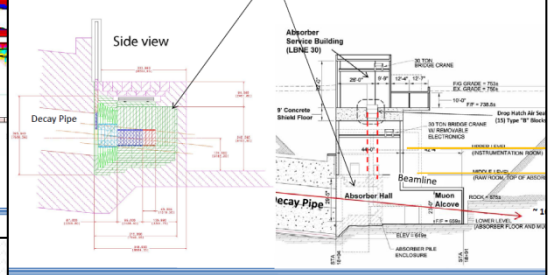


LBNE CD-1 Director's Review – 26-30 March 2012

Absorber Complex – Longitudinal Section

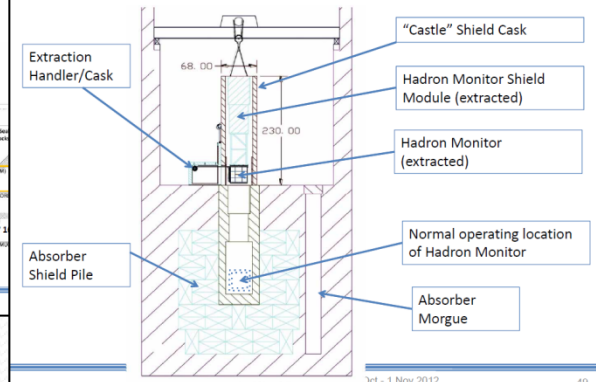
The Absorber is conceptually designed for 2.3 MW

A specially designed pile of aluminum, steel and concrete blocks, some of them water cooled which must contain the energy of the particles that exit the Decay Pipe.



LBNE CD-1 DOE Review – 30 Oct - 1 Nov 2012

Absorber Hall: Hadron Monitor Replacement Scheme



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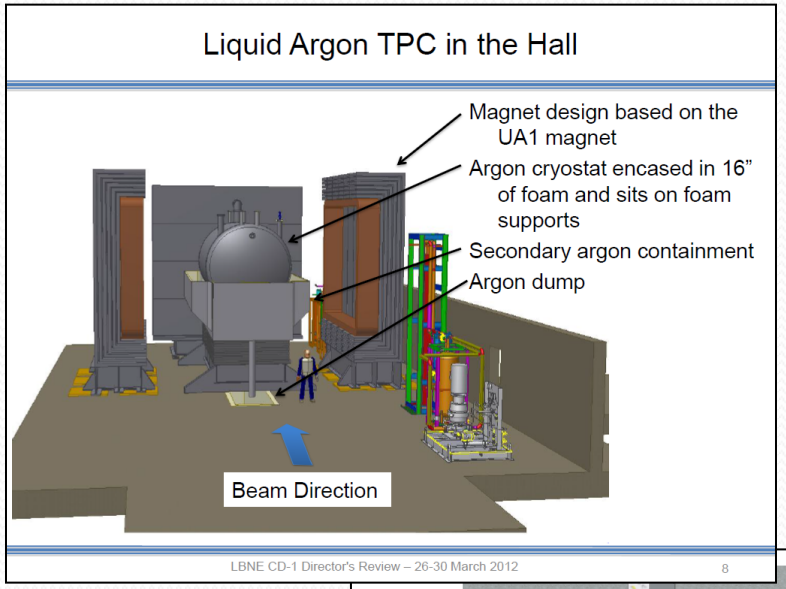
Highly-Capable Near Detector System



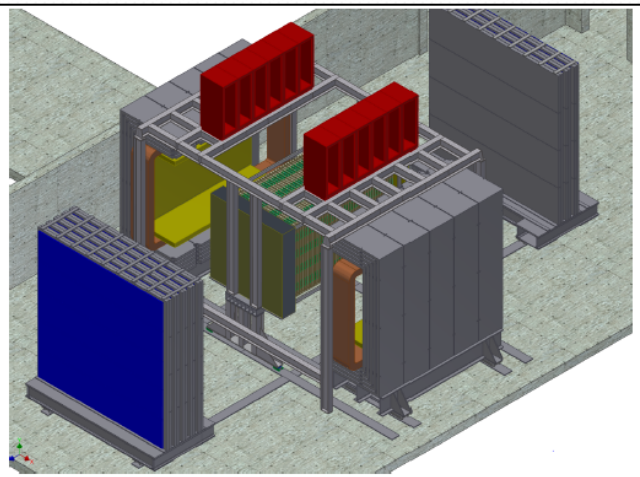


Figure 4–19: Schematic drawing of the FGT in the Near Detector Hall with the magnet opened up to show the STT, ECAL, and MuID

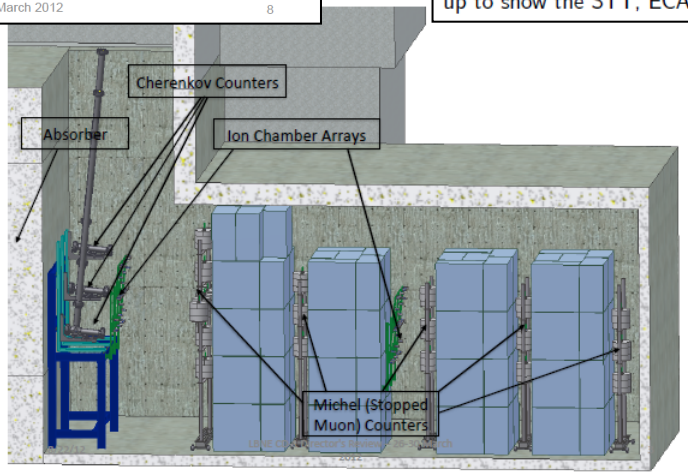
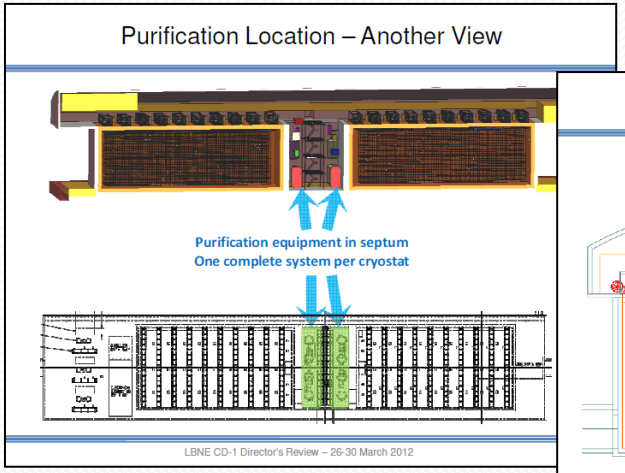
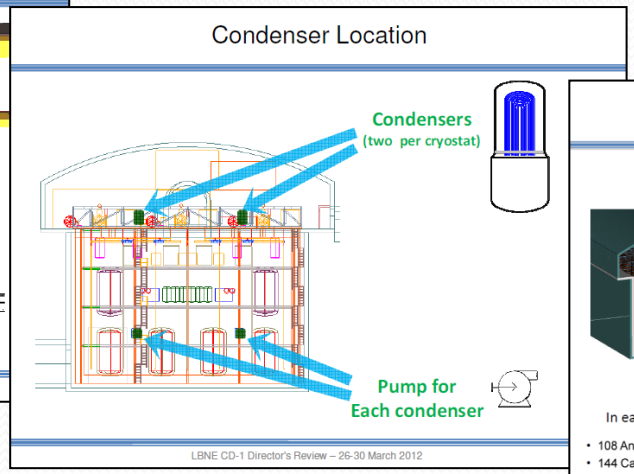
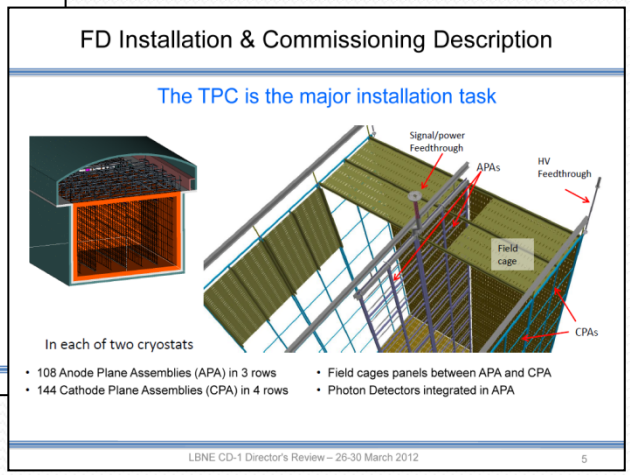


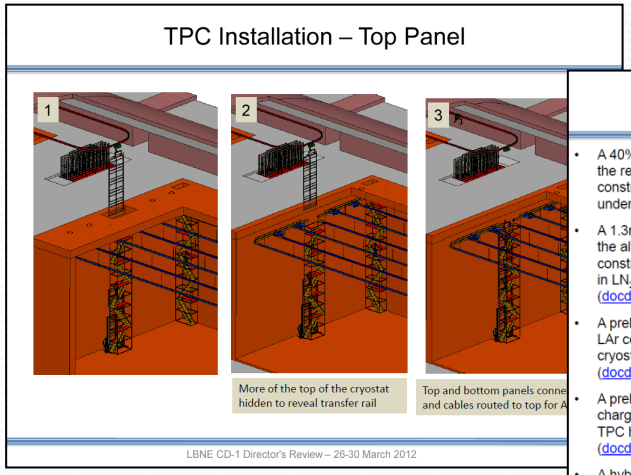
Figure 1–4: A model of the three muon monitor systems placed downstream of the absorber, in the muon alcove.

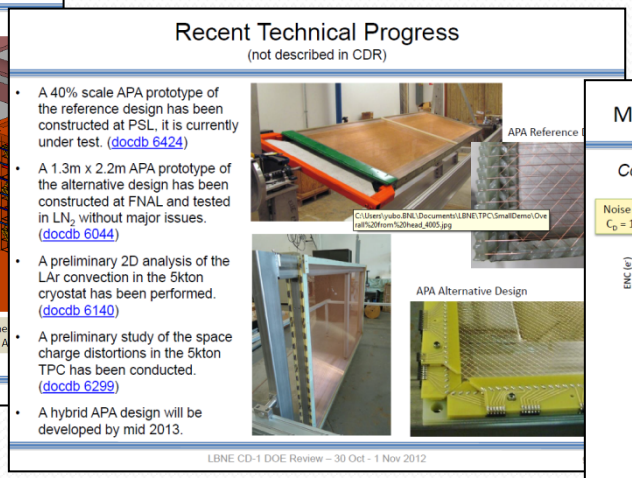
34 kt LAr Far Detector @ 4300 mwe Depth

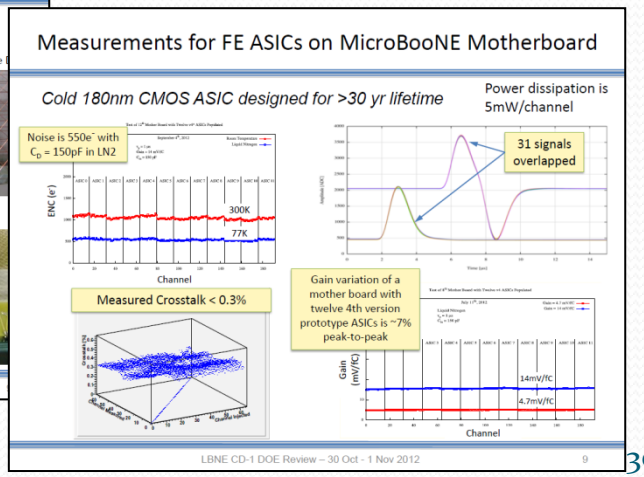




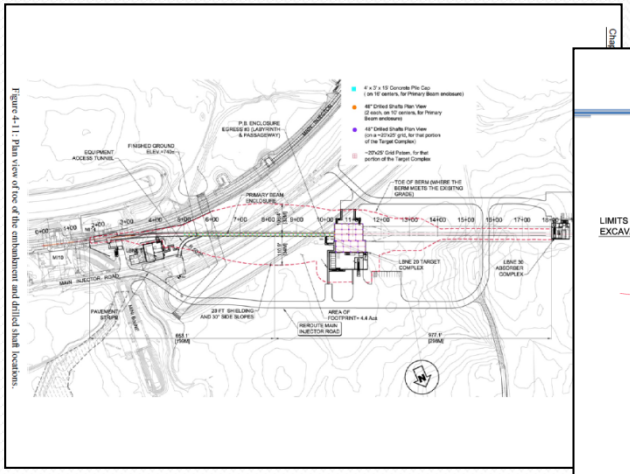


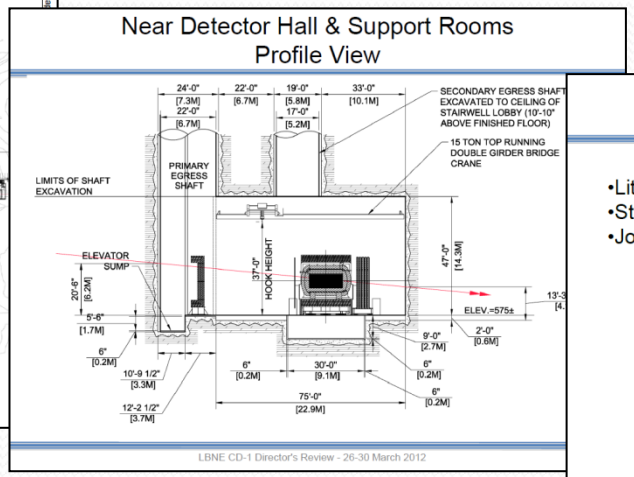


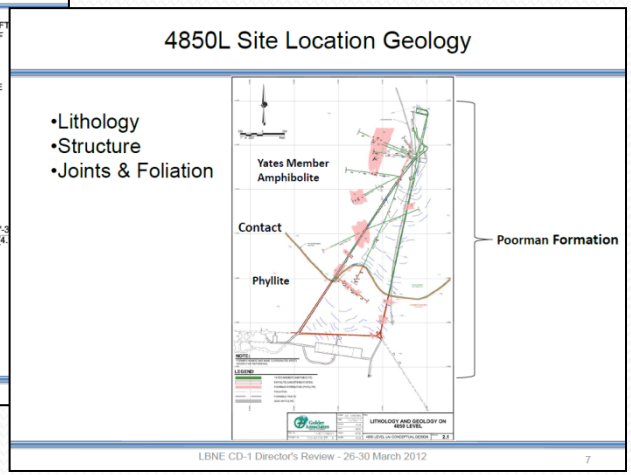


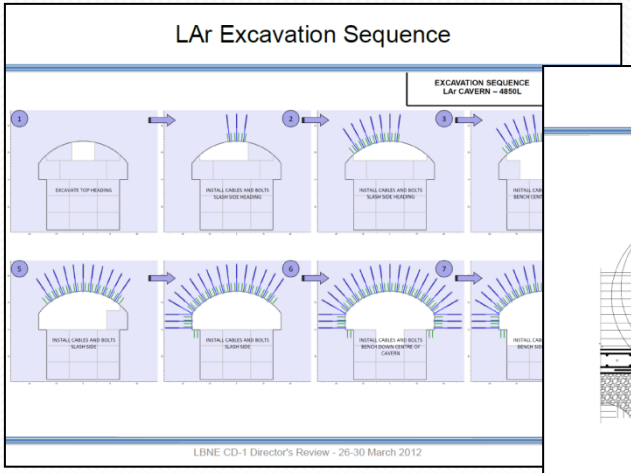


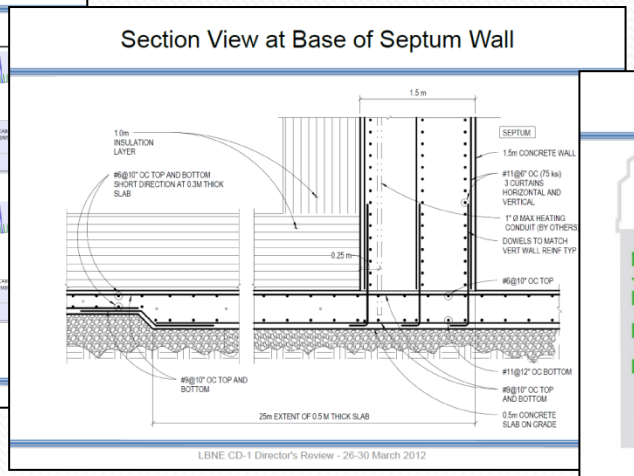
Civil Engineering for Beam and Deep Far Detector

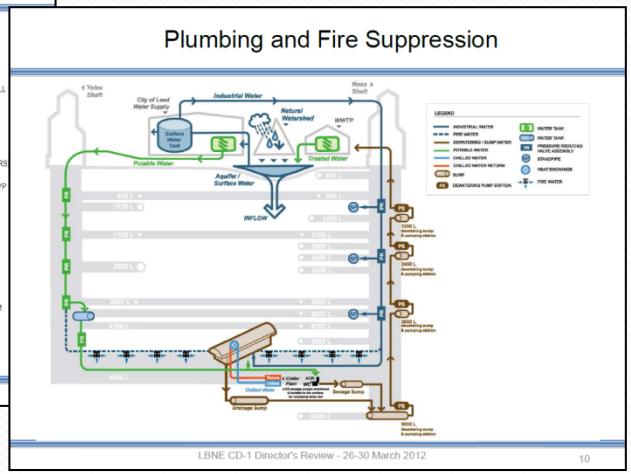






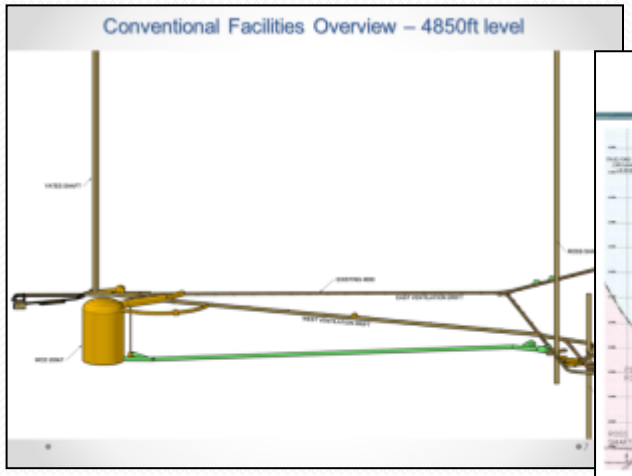


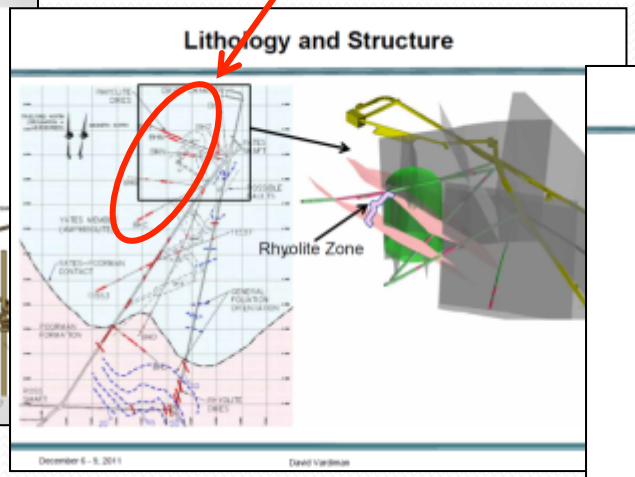


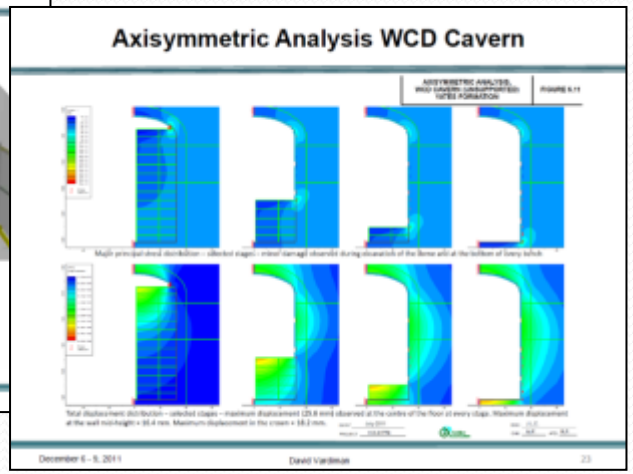


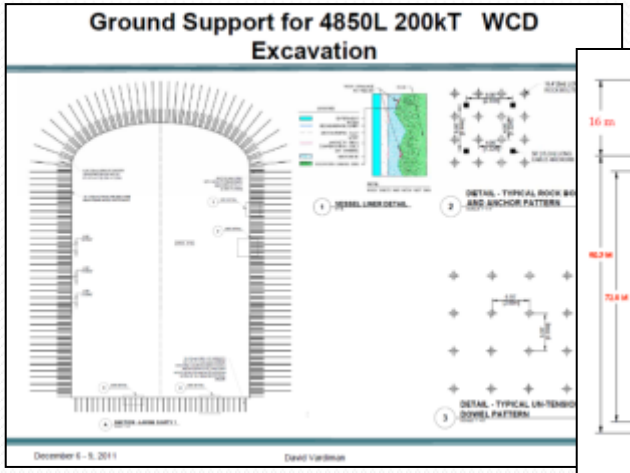
And …. we also have a design for a 200 kt (fiducial) Water Cherenkov Detector

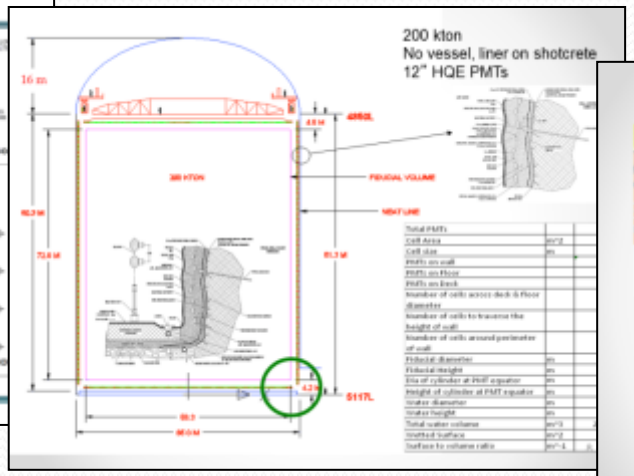
Space for several more 200 kt modules

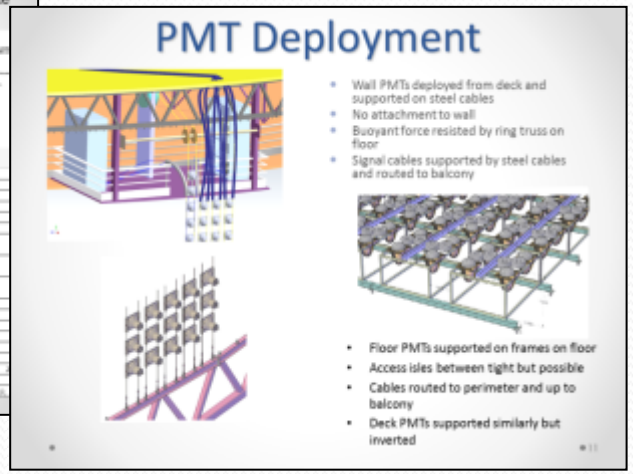








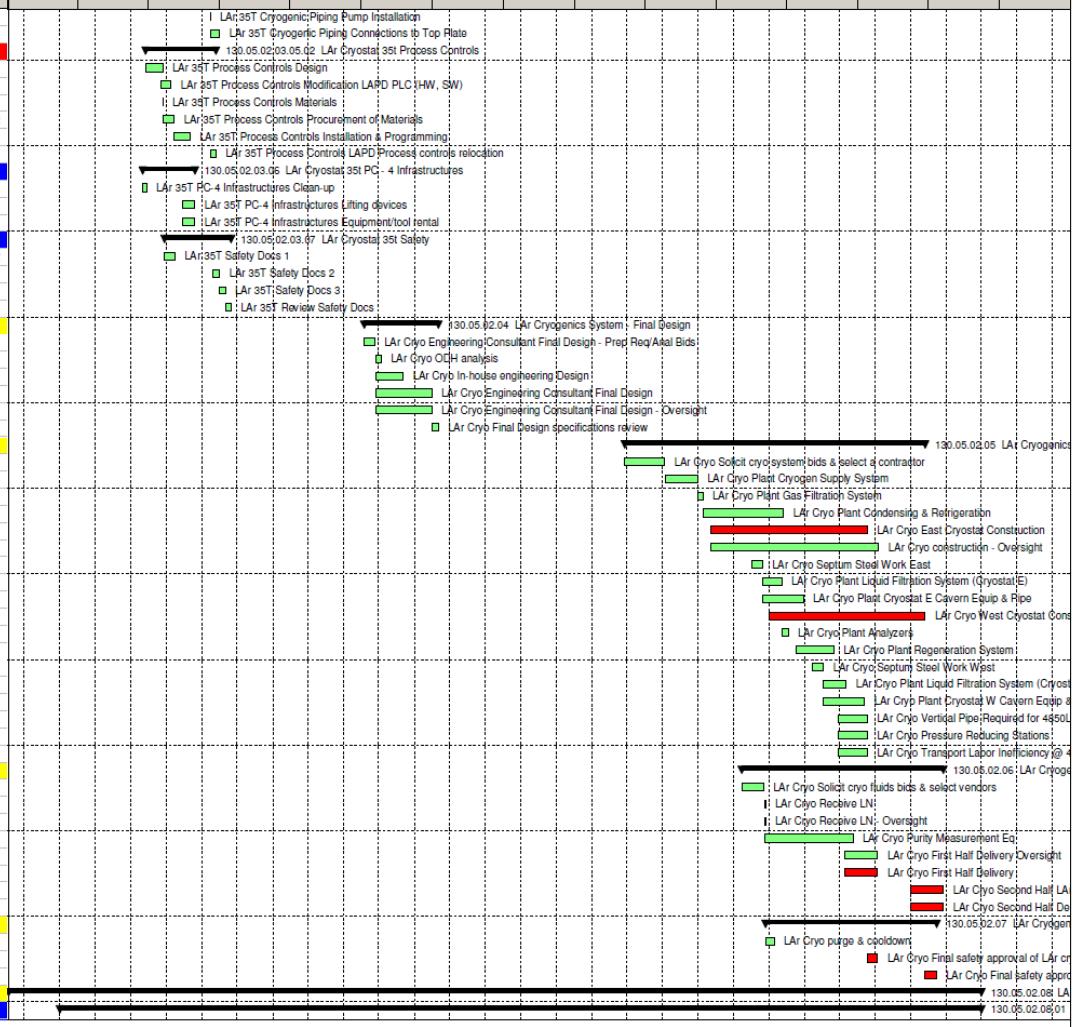




A Complete Resource-Loaded Schedule

Liquid Argon 4850L Accelerated | LBNE Liquid Argon | 09-Mar-12 09:19

Activity ID	Activity Name	Original Duration	Start	Finish
13005.02.03.05.01.09	LAr 35T Cryogenic Piping Pump Installation	2	12-Nov-12	13-Nov-12
13005.02.03.05.01.13	LAr 35T Cryogenic Piping Connections to Top Plate	30	14-Nov-12	02-Jan-13
130.05.02.03.05.02	**LAr Cryostat 35t Process Controls**	**249**	**15-Dec-11**	**11-Dec-12**
13005.02.03.05.02.01	LAr 35T Process Controls Design	60	15-Dec-11	14-Mar-12
13005.02.03.05.02.06	LAr 35T Process Controls Modification LAPD PLC (HW, SW)	40	05-Mar-12	27-Apr-12
13005.02.03.05.02.03	LAr 35T Process Controls Materials	1	15-Mar-12	15-Mar-12
13005.02.03.05.02.02	LAr 35T Process Controls Procurement of Materials	40	15-Mar-12	09-May-12
13005.02.03.05.02.04	LAr 35T Process Controls Installation & Programming	60	10-May-12	03-Aug-12
13005.02.03.05.02.07	LAr 35T Process Controls LAPD Process controls relocation	20	12-Nov-12	11-Dec-12
130.05.02.03.06	**LAr Cryostat 35t PC - 4 Infrastructures**	**188**	**01-Dec-11**	**29-Aug-12**
13005.02.03.06.01	LAr 35T PC-4 Infrastructures Clean-up	15	01-Dec-11*	21-Dec-11
13005.02.03.06.02	LAr 35T PC-4 Infrastructures Lifting devices	45	27-Jun-12	29-Aug-12
13005.02.03.06.03	LAr 35T PC-4 Infrastructures Equipment/tool rental	45	27-Jun-12	29-Aug-12
130.05.02.03.07	**LAr Cryostat 35t Safety**	**236**	**22-Mar-12**	**28-Feb-13**
13005.02.03.07.01	LAr 35T Safety Docs 1	40	22-Mar-12	16-May-12
13005.02.03.07.02	LAr 35T Safety Docs 2	20	28-Nov-12	03-Jan-13
13005.02.03.07.04	LAr 35T Safety Docs 3	20	03-Jan-13	31-Jan-13
13005.02.03.07.03	LAr 35T Review Safety Docs	20	01-Feb-13	28-Feb-13
130.05.02.04	**LAr Cryogenics System - Final Design**	**261**	**16-Jan-15**	**01-Feb-16**
13005.02.04.01	LAr Cryo Engineering Consultant Final Design - Prep Req/Anal Bids	40	16-Jan-15	13-Mar-15
13005.02.04.06	LAr Cryo ODH analysis	20	17-Mar-15	13-Apr-15
13005.02.04.07	LAr Cryo In-house engineering Design	100	17-Mar-15	05-Aug-15
13005.02.04.04	LAr Cryo Engineering Consultant Final Design	200	17-Mar-15	30-Dec-15
13005.02.04.05	LAr Cryo Engineering Consultant Final Design - Oversight	200	17-Mar-15	30-Dec-15
13005.02.04.08	LAr Cryo Final Design specifications review	20	04-Jan-16	01-Feb-16
130.05.02.05	**LAr Cryogenics System - Construction**	**1063**	**20-Sep-18**	**14-Dec-22**
13005.02.05.01	LAr Cryo Solicit cryo system bids & select a contractor	140	20-Sep-18	12-Apr-19
13005.02.05.15	LAr Cryo Plant Cryogen Supply System	118	16-Apr-19	01-Oct-19
13005.02.05.16	LAr Cryo Plant Gas Filtration System	18	02-Oct-19	25-Oct-19
13005.02.05.21	LAr Cryo Plant Condensing & Refrigeration	287	28-Oct-19	16-Dec-20
13005.02.05.05	LAr Cryo East Cryostat Construction	555	02-Dec-19	17-Feb-22
13005.02.05.24	LAr Cryo construction - Oversight	600	02-Dec-19	21-Apr-22
13005.02.05.13	LAr Cryo Septum Steel Work East	39	07-Jul-20	28-Aug-20
13005.02.05.17	LAr Cryo Plant Liquid Filtration System (Cryostat E)	68	31-Aug-20	07-Dec-20
13005.02.05.19	LAr Cryo Plant Cryostat E Cavern Equip & Pipe	143	31-Aug-20	29-Mar-21
13005.02.05.09	LAr Cryo West Cryostat Construction	551	05-Oct-20	14-Dec-22
13005.02.05.23	LAr Cryo Plant Analyzers	20	08-Dec-20	08-Jan-21
13005.02.05.22	LAr Cryo Plant Regeneration System	139	15-Feb-21	30-Aug-21
13005.02.05.14	LAr Cryo Septum Steel Work West	39	12-May-21	07-Jul-21
13005.02.05.18	LAr Cryo Plant Liquid Filtration System (Cryostat W)	85	08-Jul-21	04-Nov-21
13005.02.05.20	LAr Cryo Plant Cryostat W Cavern Equip & Pipe	142	08-Jul-21	02-Feb-22
13005.02.05.10	LAr Cryo Vertical Pipe Required for 4850L	100	22-Sep-21	17-Feb-22
13005.02.05.11	LAr Cryo Pressure Reducing Stations	100	22-Sep-21	17-Feb-22
13005.02.05.12	LAr Cryo Transport Labor Inefficiency @ 4850L	100	22-Sep-21	17-Feb-22
130.05.02.06	**LAr Cryogenic Fluids Procurement**	**714**	**13-May-20**	**20-Mar-23**
13005.02.06.01	LAr Cryo Solicit cryo fluids bids & select vendors	80	13-May-20	04-Sep-20
13005.02.06.10	LAr Cryo Receive LN	5	08-Sep-20	14-Sep-20
13005.02.06.11	LAr Cryo Receive LN - Oversight	5	08-Sep-20	14-Sep-20
13005.02.06.09	LAr Cryo Purity Measurement Eq	315	08-Sep-20	08-Dec-21
13005.02.06.04	LAr Cryo First Half Delivery Oversight	115	27-Oct-21	14-Apr-22
13005.02.06.03	LAr Cryo First Half Delivery	115	27-Oct-21	14-Apr-22
13005.02.06.07	LAr Cryo Second Half LAr Delivery	115	04-Oct-22	20-Mar-23
13005.02.06.08	LAr Cryo Second Half Delivery Oversight	115	04-Oct-22	20-Mar-23
130.05.02.07	**LAr Cryogenics System - Checkout**	**603**	**15-Sep-20**	**13-Feb-23**
13005.02.07.03	LAr Cryo purge & cooldown	30	15-Sep-20	26-Oct-20
13005.02.07.01	LAr Cryo Final safety approval of LAr cryo system #1	40	18-Feb-22	14-Apr-22
13005.02.07.02	LAr Cryo Final safety approval of LAr cryo system #2	40	15-Dec-22	13-Feb-23
130.05.02.08	**LAr Cryogenics Management**	**3445**	**12-Jan-10**	**29-Sep-23**
130.05.02.08.01	**LAr Cryogenics Project Management**	**3261**	**01-Oct-10**	**29-Sep-23**



Actual Work | Critical Remaining Work | Summary
Remaining Work | Milestone

TASK filter: No Obligations.

(c) Primavera Systems, Inc.

Complete Design of LBNE was Independently Reviewed and Found to be Sound

Issued April 23, 2012

Fermilab

Final Rep

Director's Independ
Design and CD-1 Rea
of the LBNE

March 26-30,

Director's Independent Conceptual Design and CD-1 Readi
March 26-30, 2012

Issued April 23, 2012

Executive Summary

This Director's review was designed to elicit the assembled committee's opinion on two primary questions. The first focus of the review was to perform an independent Conceptual Design review of the LBNE project to verify that the design is technically adequate, and should achieve the Project's scientific goals. The second focus was to perform a CD-1 Readiness review, with a focus on the project's cost, schedule, management, and ES&H.

The committee finds that the Conceptual Design for the LBNE project is sound, and should achieve the Project's scientific goals. Our determination is that the level of technical detail across the entire breadth of the LBNE project is sufficient to address the question of overall capability to achieve the scientific goals, as appropriate for this stage of the project. There are a number of components of the project that have advanced well beyond the conceptual stage.

The committee is confident that the LBNE project can be ready for a CD-1 review on the time scale given to the committee, the summer of 2012, if issues related to the funding profile and the resulting schedule are resolved. The management systems and documentation for the project are appropriate for a CD-1 review.

However…

- Last year US funding agency (DOE) asked us to stage LBNE construction and gave us a budget of $867M for the first phase
  - They also encouraged us to develop new partnerships to maximize the scope of the first stage.
- We chose to proceed with emphasis on the most important aspects of the experiment: 1300 km baseline and the full capability beam
  - With just the DOE budget, the far detector would be 10 kt LAr TPC at the surface.
- An external review panel recommended this phase 1 configuration.
- DOE approved "CD-1" in December 2012 for this phase-1 scope.
- Our plan continues to be to build the full scope originally planned, and are working with domestic and international partners to make the first phase as close as possible to the original goal.

DOE Critical Decisions

• CD-0 ("Mission Need") approves the need for the project.	Jan 2010
• CD-1 ("Alternative Selection and Cost Range") approves overall design, cost and schedule.	Dec 2012 (*for phase 1*)
• CD-2 ("Performance Baseline") approves the precise technical design, cost and schedule.	*Early 2017*
• CD-3A ("Approve Long-Lead Item Procurements") approves early start of selected parts of the project.	*Early 2016*
• CD-3 ("Start of Construction") approves the start of construction.	*Late 2017*
• CD-4 ("Project Completion") approves transition to operations.	*2023*

lbne-doc-6681

Critical Decision 1
Approve Alternative Selection and Cost Range
of the
Long Baseline Neutrino Experiment (LBNE) Project
(Line Item Project 11-SC-40)
at the
Fermi National Accelerator Laboratory and
Sanford Underground Research Facility
Office of High Energy Physics
Office of Science

Purpose

The purpose of this paper is to document the review and approval by the DOE Office of Science Energy Systems Acquisition Advisory Board-equivalent for Critical Decision 1 (CD-1) "Approve Alternative Selection and Cost Range" for the Long Baseline Neutrino Experiment (LBNE) Project at the Fermi National Accelerator Laboratory (Fermilab) and Homestake Mine

Critical Decision 1, Approve Alternative Selection and Cost Range
for the LBNE Project

Approval

Based on the information presente din this document and at the ESAAB review, I approve Critical Decision 1, Approve Alternative Selection and Cost Range for the Long Baseline Neutrino (LBNE) Project.

William Brinkman, Acquisition Executive
Director, Office of Science

12/10/12
Date

Tailoring of the scope definition prior to CD-2 to enhance scientific capabilities may also be considered. The physics opportunities offered by the beam from Fermilab and the long baseline may attract the support of other agencies both domestic and international. Contributions from such other agencies offer alternative funding scenarios that could enhance the science capabilities of the Project. If additional domestic or international funding commitments are secured sufficiently prior to CD-2, the DOE LBNE Project baseline scope could be refined before CD-2 to include scope opportunities such as a Near Neutrino Detector complex at Fermilab or an underground location at SURF for the far detector.

the neutrino mass states, would not be obtained, compromising the ability to understand the matter-antimatter asymmetry and resulting dominance of matter in the universe.

To meet the scientific and technical objectives for the LBNE experiment, the following draft key performance parameters have been developed.

http://lbne2-docdb.fnal.gov/cgi-bin/RetrieveFile?docid=6681;filename=LBNE%20CD-1%20appr.pdf

Considerations regarding a phased approach

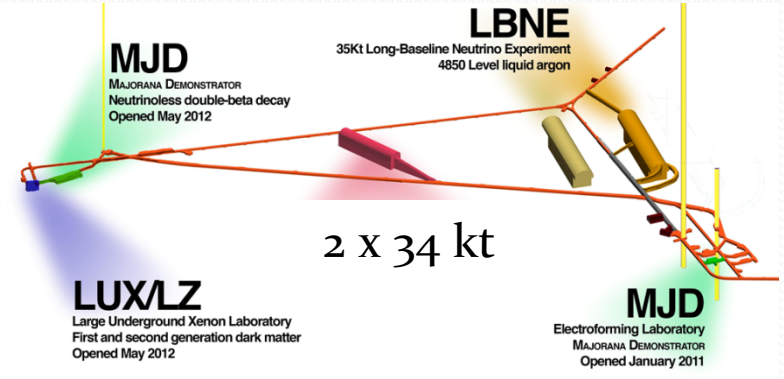
- Staging the Near Detector is "straightforward"
  - Essentially a stand-alone project of cost ~$150M*
  - No serious loss of physics if it starts operation later than the beam and far detector.

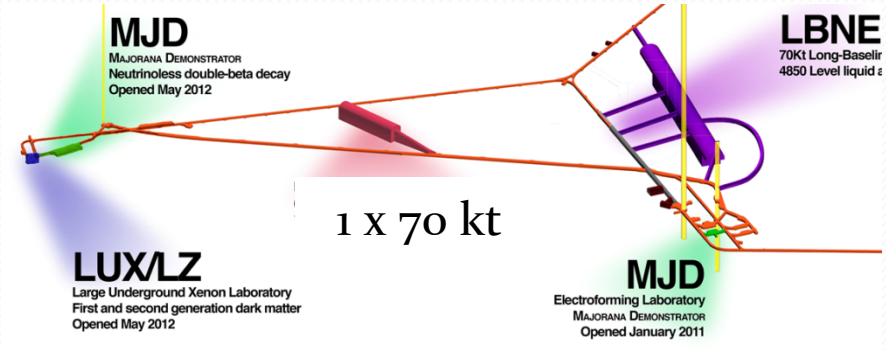
- Staging the Far Detector is more complicated
  - Detector at the surface is not a real step towards a larger underground detector.
    => Important to start with an underground detector.
  - Incremental cost to place detector underground is ~$150M*

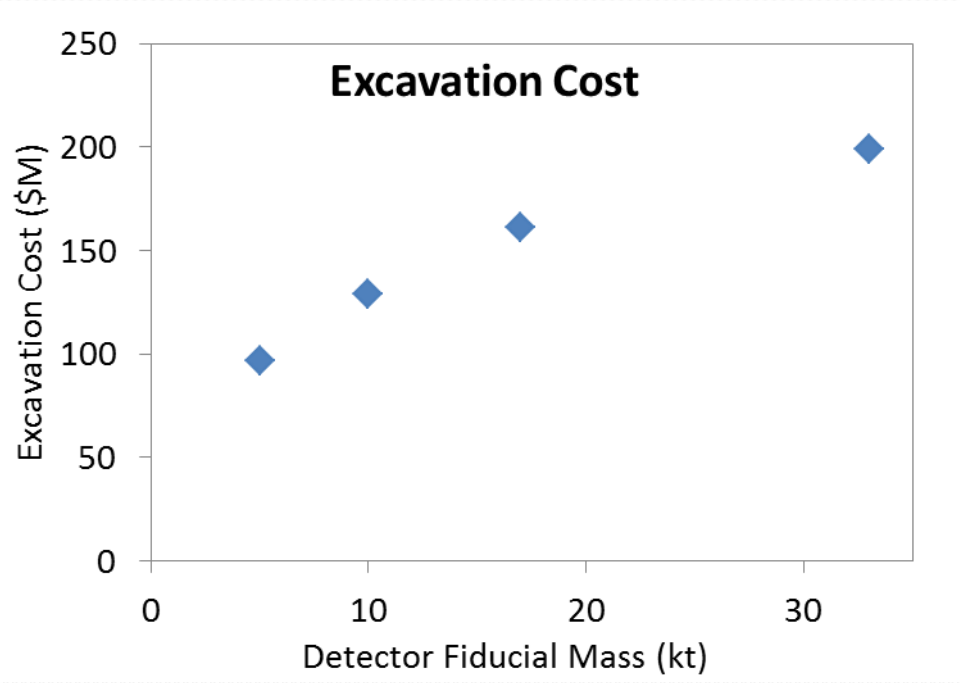
*US Accounting

Considerations regarding a phased approach

- Ideally, we should excavate a larger cavern than detector size supported by initial budget.



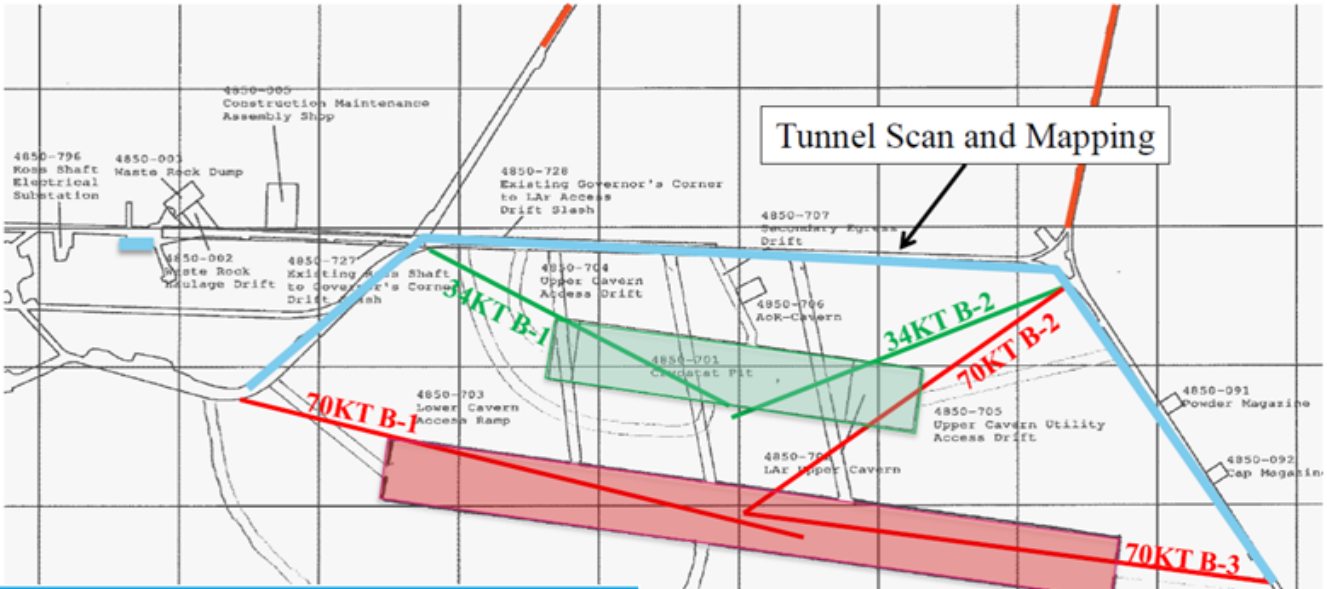




Planning for Underground Location

- We are planning to do geotechnical investigation of the LBNE detector site at the 4850 level, which is on critical path.

Conceptual 4850 LBNE Exploration Program



Exploration Summary			
70KT Excavation		34KT Excavation	
Bore	Length (ft)	Bore	Length (ft)
B-1	950	B-1	475
B-2 (angled)	750	B-2	500
B-3	950		

Previous Mapping – LFA 2009

Proposed Mapping

Goal for LBNE Phase 1

- Together with additional partners, build:
  - Neutrino beam for 700 kW, upgradeable to 2.3 MW
  - Highly-capable near neutrino detector
  - >10 kt fiducial mass LAr far detector at
    A baseline of 1300 km
    A depth of 4300 m.w.e.
- The world-wide community can build upon the substantial investment planned by the US to make LBNE a world facility for neutrino physics, astrophysics, and searches for non-conservation of baryon number.

Together we can do more than we can do separately.

International Discussions

- We are in discussion with a number of potential non-US partners, both physics groups and funding agencies, in:
  - Brazil
  - India
  - Italy
  - UK
- LBNE and LAGUNA-LBNO have established a task force
- ICARUS/INFN groups in the process of joining LBNE
- We have also had preliminary discussions with:
  - CERN
  - Dubna
- We are hoping to initiate discussions with others:
  - Japan
  - China
  - Additional countries in the Americas, Asia and Europe
- Also exploring how to engage domestic funding agencies beyond the DOE

European Strategy and CERN

European Strategy for Particle Physics:

Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector.

CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.

- Formally adopted at the special European Strategy Session of the Council in Brussels on 30 May 2013.
- The role of CERN will by key. The next step is for CERN to establish a platform from which European groups can participate in long-baseline physics. ...hopefully in the US!

Flexibility in DOE Project Management System

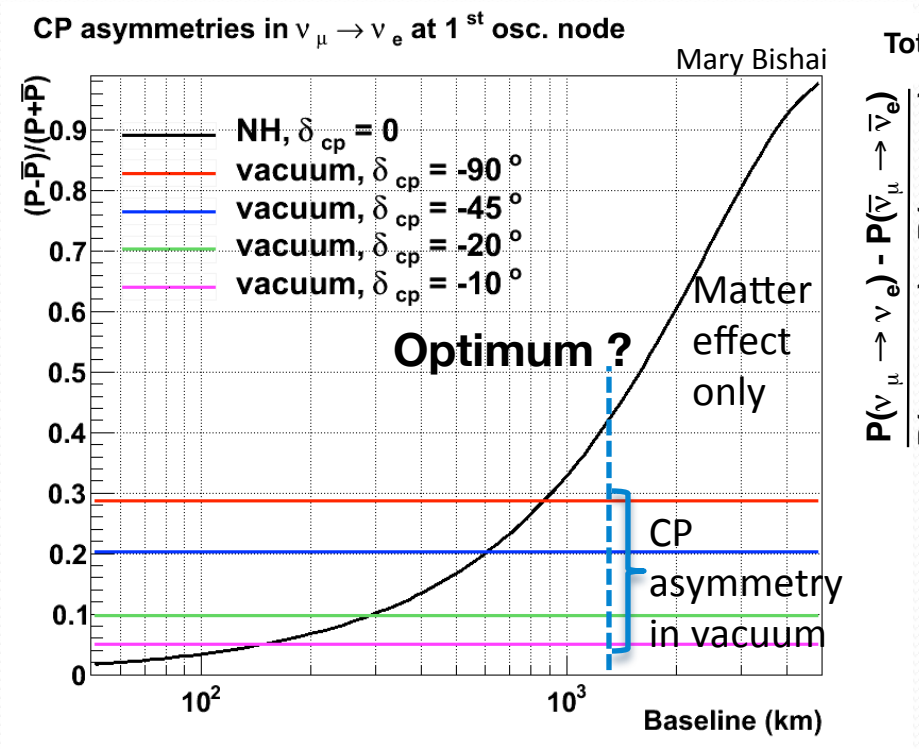
- The DOE Project Management System ("CD process") has more flexibility than is generally understood or used.
- DOE management has encouraged us to
  - *first* make a plan with international partners that makes sense for LBNE, and
  - *then* to work with them to make the DOE system work to support the plan.
- Examples of potential flexibility include the ability to:
  - Change detailed scope between CD-1 and CD-2
  - Delay CD-2 until ready
  - Stagger CD-2/3/4 for different parts of the project, e.g. beam vs. far detector

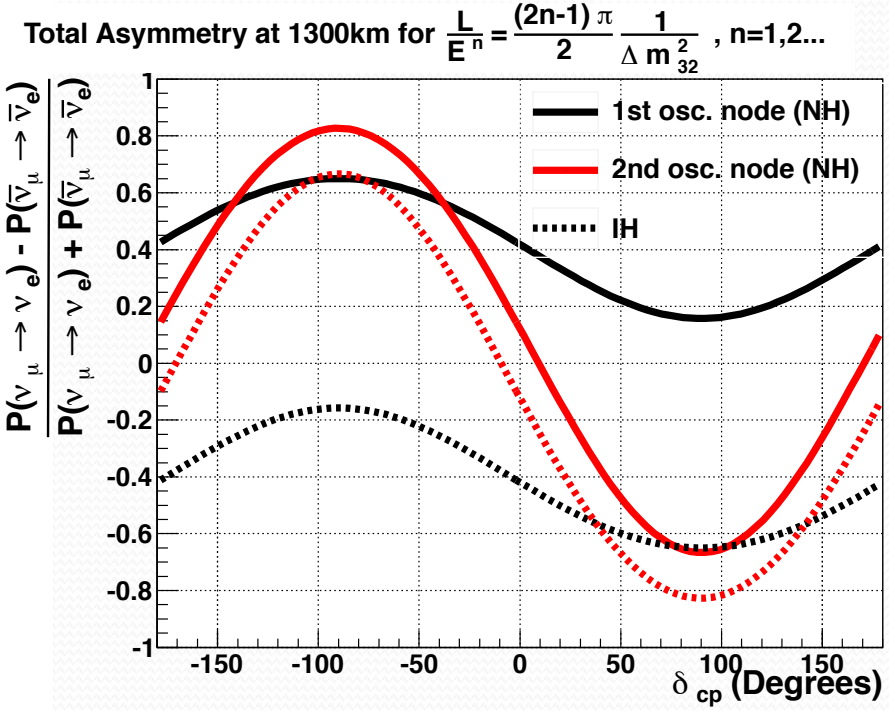
Summary

- CP violation parameter, mass hierarchy, non-standard interactions likely inaccessible to current generation experiments
  - **Need longer baseline and very large instrumented targets for a comprehensive program**
- Large detectors also probe physics not accessible any other way
  - Proton decay (Grand Unified Theories)
  - Supernova burst neutrinos from intra-galactic distances
- LBNE has received approval to begin this program
  - It will be the primary US HEP facility for the 2020's
  - With a budget of $867M we are proceeding with the most important aspects in the first phase and actively seeking partners to expand the scope
- LBNE will develop into a world center for neutrino physics to complement those for hadron/lepton colliders

Back Up

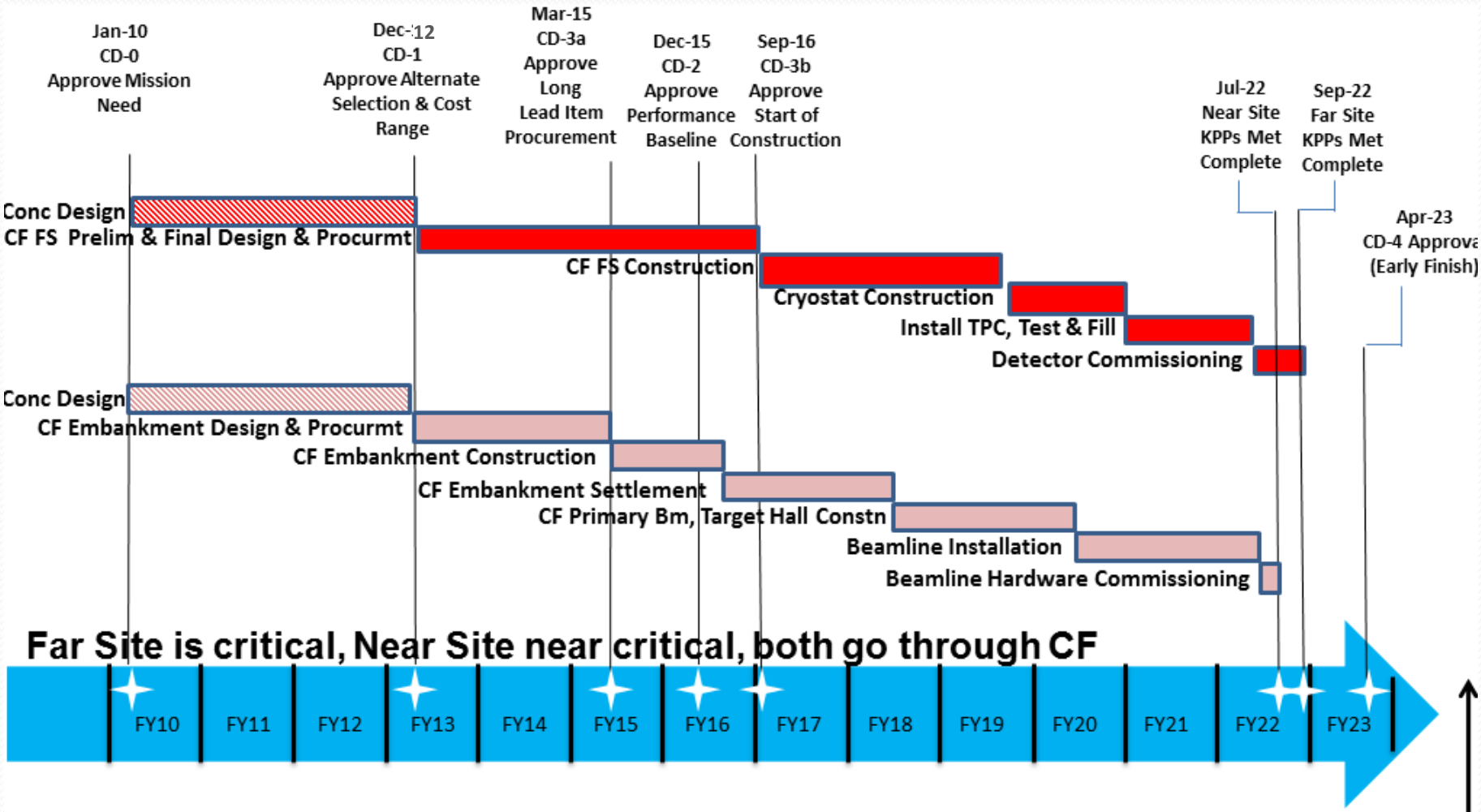
Why 1300 km: Baseline Optimization





- ✧ Optimum is achieved when the asymmetry due to the matter effect is larger than the largest CP effect, but does not saturate the total asymmetry.
- ✧ At the first maximum at the optimum baseline there is no degeneracy.

LBNE DOE Schedule (CD-1 Review)



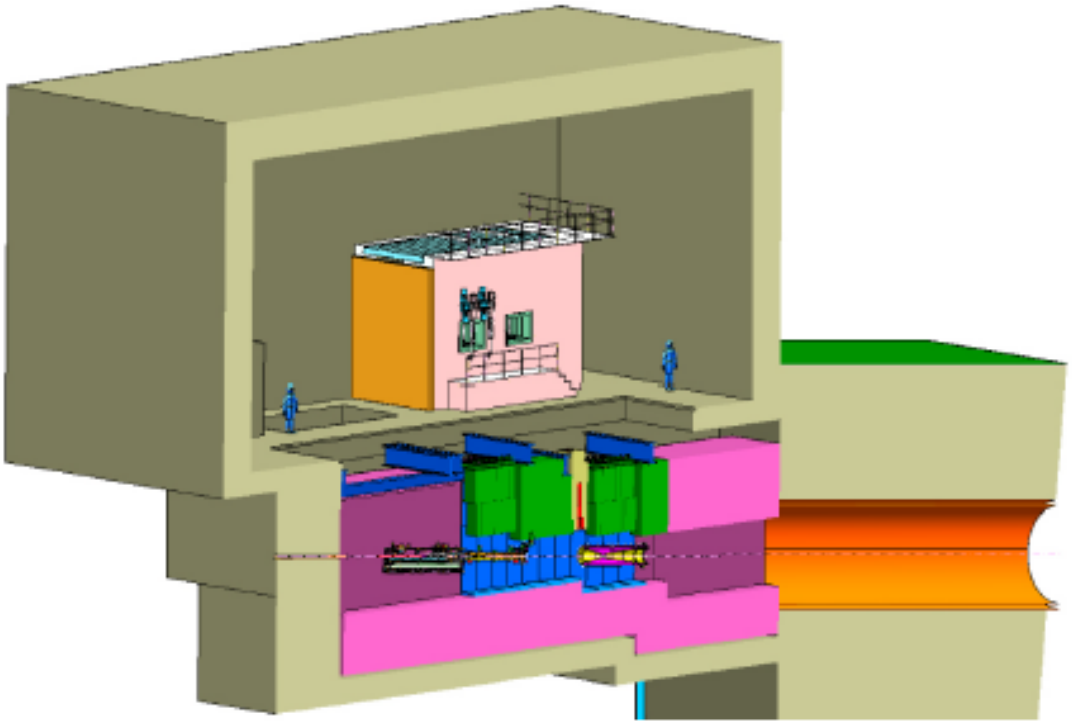
Affected

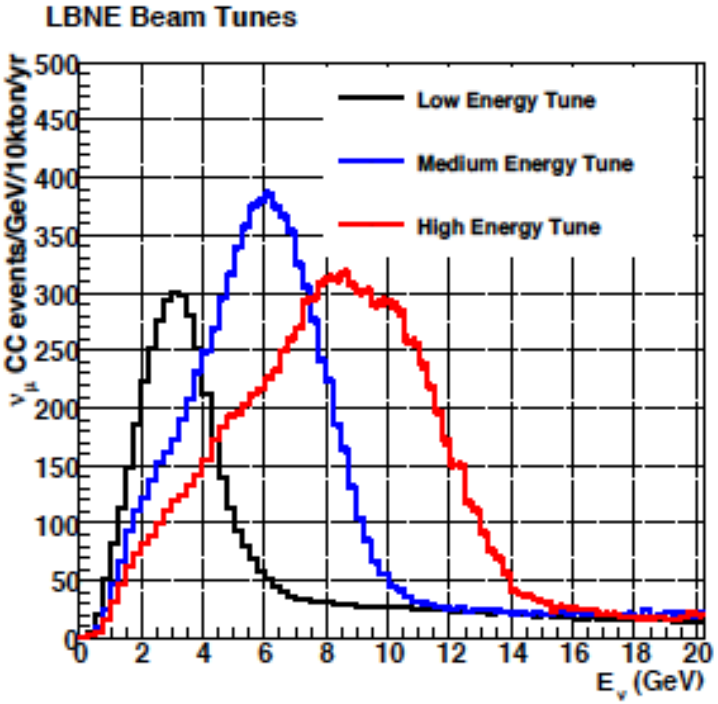
2 yr schedule contingency on early finish

LBNE Reference Beam Design

Beam Parameter	Value
Protons per cycle	4.9×10^{13}
Cycle time (120 GeV)	1.33 sec
Pulse duration	1.0×10^{-5} sec
Proton beam energy	60 to 120 GeV
Beam power at 120 GeV	708 kW
Efficiency (beam to LBNE)	63%
Protons at target per year	7.3×10^{20}
Beam size at focus	0.15 cm
Beam divergence x,y	0.017 mrad

Using NuMI focusing = tunable beam energies





The LBNE ν beam improvements under consideration:

Impact on $\nu_\mu \rightarrow \nu_e$ appearance rates at the far site:

Changes	0.5-2GeV	2-5GeV
Decay pipe air $\rightarrow$ He	1.07	1.11
DP length 200m$\rightarrow$ 250m	1.04	1.12
Horn current 200kA $\rightarrow$ 230kA	1.00	1.12
E_p 120 $\rightarrow$ 80GeV,700kW	1.14	1.05
Tgt NuMI $\rightarrow$ Be	1.00	1.03
DP diameter =4m $\rightarrow$ 6m	1.06	1.02
Total	1.3	1.5

Costs for the options have been developed